Back-Mirror: Back-of-Device One-Handed Interaction on Smartphones

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Abstract

We present *Back-Mirror*, a low-cost camera-based approach for widening the interaction space on the back surface of a smartphone by using mirror reflection. *Back-Mirror* consists of two main parts: a smartphone accessory with a mirror that can reflect the back surface to the rear-facing camera of the phone, and a computer-vision algorithm for gesture recognition based on the visual pattern on the back surface. Our approach captures the finger position on the back surface, and tracks finger movement with higher resolution than the previous methods. We further designed a set of intuitive gestures that can be recognized by *Back-Mirror*, including swiping up, down, left and right, tapping left, middle, right, and holding gestures. Furthermore, we created applications of Back-of-device, such as game, media player, photo gallery, and unlock mechanism, allowing users to experience the use of *Back-Mirror* gestures in the real-life scenarios.

Keywords: mobile interaction, back-of-device, gestures, motion sensing, camera, smartphone.

Concepts: • **Computing methodologies ~ Image manipulation;** *Computational photography;*

1 Introduction

Back-of-device (BoD) mobile interaction has attracted a lot of research interests, due to its capability of easing one-handed operation. Research found that one-handed interaction is a preferable operation mode for people to use a handheld device [Müllernet al. 2015], as one-handed operation offers benefits by freeing a hand for other uses, such as holding a train handle or carrying a briefcase. However, while holding and operating the device with one hand, the thumb is normally the only finger to touch the screen. The thumb suffers from a reachability problem[Li et al. 2013]: the limited movement of the thumb causes relatively slow and less accurate interaction. On the other hand, the index finger with bigger range of movement usually remains idle on the back of the device. Thus, BoD interaction is suggested to leverage the unused backside space of the device and the idle index finger to facilitate mobile interactions with only one hand.

In this paper we present *Back-Mirror* (Figure 1), a low-cost camera-based approach using the built-in rear-facing camera of a smartphone and a small reflecting mirror for BoD gesture

Figure 1: *Back-Mirror in use of media player*

recognition based on the visual pattern on the back surface of the phone. *Back-Mirror* is capable to detect BoD swiping and tapping gestures directly on the back surface of the device. Our research aims to exploring one-handed back-of-device interaction with a low-cost camera-based method. Comparing with the previous methods which mostly utilized the built-in/external sensors (e.g., touch pad on the back, accelerometer, and magnetic sensor), our approach allows back-of-device interaction with a higher resolution input without costly external sensors.

2 Related Works

In recent years, BoD interaction has been widely proposed for one-handed interaction with smartphones. Up to date, the existing efforts on enabling BoD interaction can be categorized into three main types: 1) Integration of external hardware (e.g., touchpad on the back surface) and a smartphone; 2) Usage of existing internal sensors (e.g., microphone, gyroscope and/or accelerometer) of the smartphone; 3) Usage of the rear-facing camera of the smartphone.

2.1 Integration of external hardware

Smartphones with touchpad on their back surface started to appear in recent years. Doogee and Leagoo [Doogee; Leagoo] have promoted their smartphones Valencia DG800 and Alaf 2, which placed touch panel on smartphone back surface. It allows users to swipe and scroll on the back of the device using their index fingers. However, most of the mainstream mobile devices still do not have such touchpads on the back surfaces, and thus do not benefit directly and practically from this integration. *Back-Mirror* was motivated for the usage of most existing smartphones to interact on the back surface with minor and low-cost attachment or modification.

2.2 Usage of internal sensors

Using internal sensors requires little modification on the existing smartphones. Karsten and Kate [2014] used the built-in microphone and gyroscope to distinguish patting of different fingers on back or side of device. Wang et al. [2006] investigated the estimation of hand pose and finger tap locations on different

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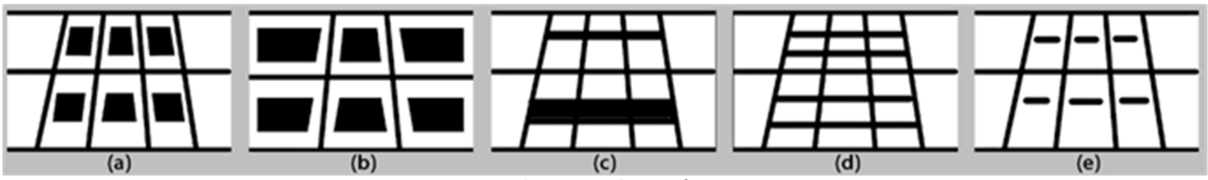

Figure 3: *Back pattern design for prototyping*

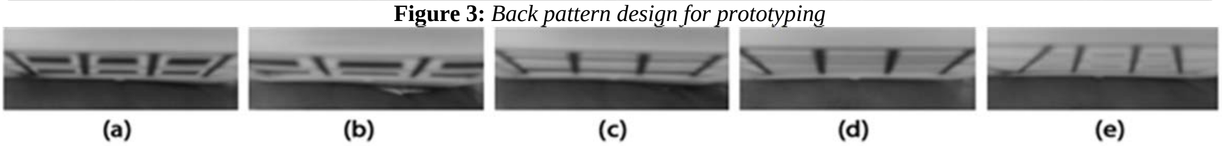

Figure 4: *Back pattern with perspective distortion*

sides of smartphone using accelerometer and gyroscope with machine learning. While most of the existing results can only support simple interaction like tapping, LensGesture [Xiao et al. 2013] is a pure software approach for BoD gesture recognition (e.g., holding and swiping) by detecting full and partial occlusion of back camera and tracking the changes of environment from image sequences. However, gestural interaction directly on the lens of the back camera could suffer from limited interaction space on the lens. OMSO [Osmo. 2015] introduced an idea for tablet interaction on table surface by attaching a reflector and a stand on an iPad. It allows children to learn and play in an innovative way on table surface with physical cards, puzzles, paper and pen. *Back-Mirror* utilizes the device back surface providing a larger input space, which allows interactions to be performed more naturally.

2.3 Usage of rear-facing camera

The rear-facing camera has also been used for gesture and posture detection at the back of smartphones. Zhihan and Alaa [2013] developed a vision-based method for in-air touchless interaction at the back of mobile devices by tracking the contour of a finger. Fisheye lenses have also been used for exploring a wider interaction space around mobile devices. Cyclops [Chan et al. 2015] used a single-piece wearable device to track a user's whole body postures from egocentric view through a fisheye lens located at the center of his/her body. Later Cyclops was modified to CyclopsRing [Chan et al. 2015], a fisheye imaging wearable device worn on hand webbing, for whole-hand gesture recognition and context-aware interaction. However, these methods required certain distance between smartphone camera and the user’s hand in order to view the whole hand, and thus are not suitable for one-handed interaction. Besides, the mid-air interaction at the back of the device could easily cause fatigue due to the lack of physical feedback. *Back-Mirror* uses the small reflector to transfer the back surface of the smartphone to the rear-facing camera, allowing one-handed and on-surface interaction.

3 Design

Back-Mirror is motivated by the following four observations. First, the index finger is nimble and usually idle when holding the smartphone with one hand. Second, most people hold the bottom part of the device while the large upper part of the backside remains unused. Third, the user’s index finger can reach most of the device backside. Fourth, the built-in camera of the smartphone remains unused mostly except photographic applications.

Back-Mirror (Figure 2a) basically consists of three main hardware parts: 1) a smartphone with a 3D printed case to attach a mirror to the device, 2) a small mirror (15mm x 15mm), and 3) a printed

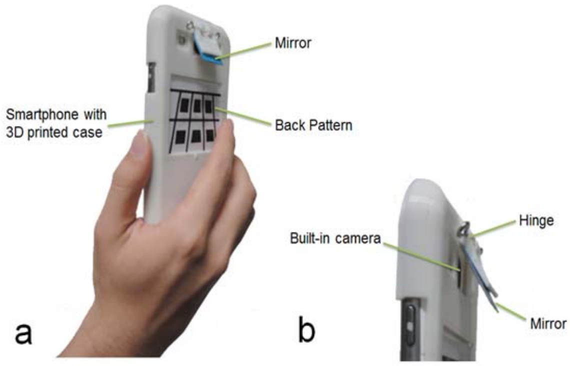

Figure 2: *Back-Mirror overview*

pattern attached on the back of the device. The mirror locates in the front of the phone’s built-in rear-facing camera with a hinge for adjusting the mirror angle (Figure 2b). The small mirror reflects the backside image to the built-in rear-facing camera. The hinge allows users to fine-tune the mirror angle so that the rear-facing camera can capture the image of the back pattern region clearly.

3.1 Back pattern

The appearance of the back surface varies among different devices. To achieve a visually consistent back surface for gesture detection, we designed and experimented different back patterns (Figure 3) to enhance the performance of *Back-Mirror*.

The mirror is attached on the smartphone with a certain angle between the flat mirror surface and device back surface. This angle causes distortion of the back pattern captured from the rear-facing camera. The smaller the angle, the less the distortion effect is. However, the captured images become darker due to the shadow of the mirror. While a larger angle could achieve brighter image capturing, the distortion becomes more significant. We found that 36-degree could strive a good balance, and lead to a sufficient brightness with less distortion.

Figure 4 shows the back patterns (a) to (e), corresponding to (a) to (e) in Figure 3, with the perspective distortion captured from the rear-facing camera. Considering the size of the index finger, the interaction area, and the size of the camera image, a back pattern with simple and clear details is essential for *Back-Mirror* gesture recognition. Patterns (c), (d), and (e) are affected greatly by perspective distortion, resulting in unclear imaging. While pattern (b) provides clear features, some details become beyond the left and the right boundaries. In the end, pattern (a) was chosen because of its clear features and suitable size for *Back-Mirror* gesture recognition.

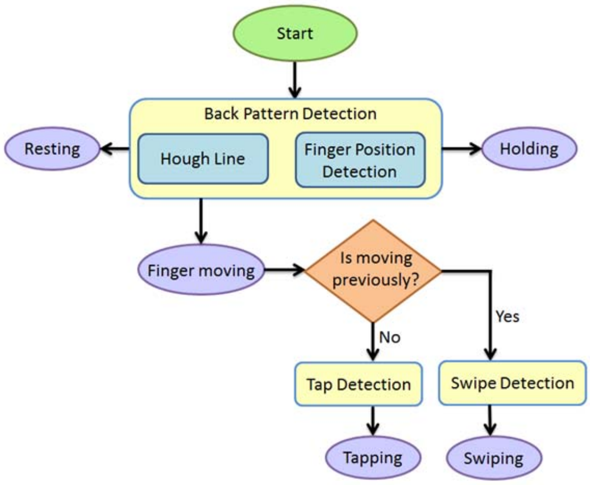

Figure 5: *Flow chart of Back-Mirror detection*

4 Algorithm

4.1 Algorithm design

There are three main parts in our algorithm for *Back-Mirror* BoD gesture recognition. Figure 5 shows the overall flow chart of *Back-Mirror* detection process with three main parts: the detection of the back pattern, tap detection, and swipe detection. First, the camera image is input for detecting the back pattern to trace the finger movement and classify the current state into three types: resting, holding, or finger moving. The state of resting indicates no finger covered on the back pattern. The state of holding means the user keeps his/her finger still on the back surface, and the state of finger moving reveals that finger movement occurs. With the detected state on the back surface of the device, the tap detection and the swipe detection are further executed in our algorithm. If the finger is moving in previous frames, which indicates swiping may occur, the process of swipe detection will be executed, while the tap detection will be activated if the finger does not move and the previous state is resting.

Back pattern detection – As the first step, the Hough line transform detects straight lines in the back pattern. If the user's finger touches the back surface, the back pattern will be partially covered, and the covered position will have no straight lines detected, and thus the empty area indicates the finger position. With the finger positions of the current and the previous frames, finger movement can be classified into the three different states: resting, holding, or finger moving. If the back pattern is not covered, it indicates the resting state; otherwise the algorithm further classifies the current movement into holding or finger moving. If the finger position remains unchanged, indicating no finger movement, the algorithm recognizes this state as holding, while both tapping and swiping gestures involve finger movement. As tapping starts from the resting state and swiping is a continuous movement, we can use the finger position in the previous frames to identify whether tapping or swiping is performed.

Tap detection – In our current implementation, the interaction area on the back surface is divided into three regions: left, middle, and right. Once the user's finger touches the device back surface,

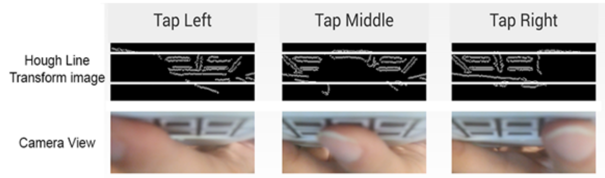

Figure 6: *Sample images of tapping (from left to right), Tap Left, Tap Middle, and Tap Right*

the Hough Line detection cannot detect any straight line in the covered region. Figure 6 shows that the detectable Tap actions include Tap Left, Tap Middle, and Tap Right, by detecting the user's finger position. Tap detection only consider the horizontal position of the finger on the back surface so that the results remain the same if the user taps on upper or lower position.

Swiping detection - The swiping detection analyzes the starting and the ending position of the finger. Swiping (Figure 7) is usually a continuous translation movement. We analyze the starting and the ending finger positions, and consider the swiping path as a straight line from the starting position to the ending position. We then analyze the length of swiping and the slope to classify swiping into Swipe Left, Swipe Right, Swipe Up, and Swipe Down.

4.2 Implementation

The algorithm of feature capturing on the back pattern was developed in Java, based on the Hough line transform [Hough. 1962]. We implemented *Back-Mirror* gestures on Samsung Galaxy S3 LTE smartphone. In the process of *Back-Mirror* detection, the camera captures 320 x 320 pixel grey image at sampling rate of 11 frames per second for algorithm processing. The functions of automatic focus and automatic white balance adjustment are disabled to avoid interference with our algorithm.

With this algorithm, the current implementation of *Back-Mirror* is able to detect eight types of gestures, including Tap Left, Tap Middle, Tap Right, Swipe Left, Swipe Right, Swipe Up, Swipe Down, and Holding as shown in Figure 8. We conducted an informal user test with 3 participants and the overall accuracy of *Back-Mirror* was 82% and could achieve over 90% with training.

5 Applications

To illustrate the feasibility and potential of *Back-Mirror*, we designed four applications: mobile gaming, media player, unlocking mechanism, and photo album. Please see the accompanying video for their demos.

Game – We designed a one-handed shooting game controlled by *Back-Mirror* gestures allowing gaming with no occlusion during the game. A player can swipe his/her finger left or right on the back surface to move an aeroplane. Tapping middle will trigger shooting.

Media Player – *Back-Mirror* gestures can be applied to media player for content navigation. Users can hold/tap to pause/play the video, and swipe left or right to play fast-forward or fast-backward the video respectively. With *Back-Mirror* gestures, navigation menu can be omitted without blocking the media content.

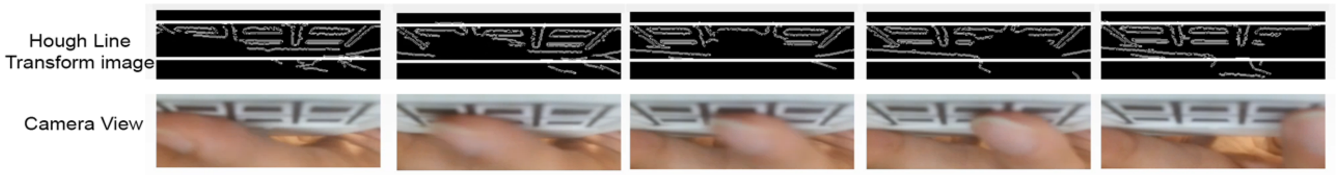

Figure 7: *Sample images of Swiping Left (from left to right)*

Unlock Mechanism – Apart from password and pin, we introduce a new unlocking mechanism with *Back-Mirror*. Users can define their own unlock sequences (e.g. Tap Left, Tap Middle, Swipe Left then Right) with *Back-Mirror* gestures and perform their defined sequences on the back, which has lower visibility than the front surface, to unlock the device.

Photo Album – This leverages the tapping, swiping, and holding gestures for one-handed photo navigation. Users can swipe left and right for previewing photos, and swipe up or down for clockwise or counterclockwise rotation, and tap or hold for zooming in and out.

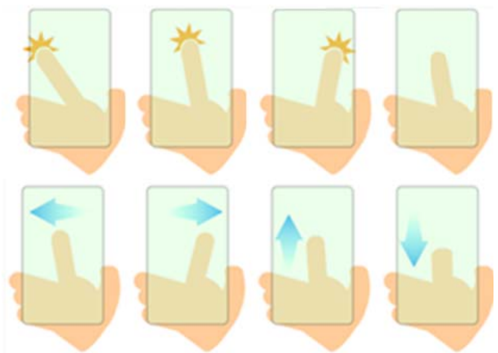

Figure 8: *Illustrations of Back-Mirror gestures. First row left to right: TAP LEFT, TAP MIDDLE, TAP RIGHT, and HOLDING. Second row left to right: SWIPE LEFT, SWIPE RIGHT, SWIPE UP, and SWIPE DOWN.*

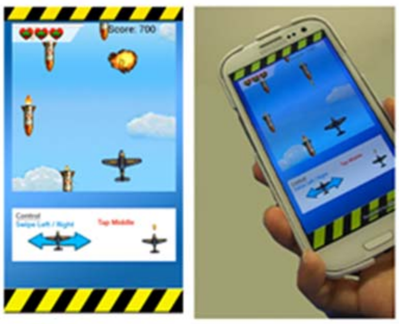

Figure 9: *Game example control by Back-Mirror gestures*

6 Discussions

The participants used *Back-Mirror* with positive experience. All of them found that *Back-Mirror* was easy to learn and to use, and expanded the interaction space. One participant said he needed a few minutes to familiarize himself with the eight *Back-Mirror* gestures and to find the best posture to comfortably perform the gestures. The participants found that it was sometimes difficult to precisely identify the middle tapping region if the hand was inclined. Overall, they revealed that the interaction was natural and intuitive and would like to use the *Back-Mirror* gestures on their smartphones.

Back-Mirror has its limitations. First, it cannot co-exist with photo taking and video recording applications due to its camera-based mechanism. Second, it is sensitive to lighting and cannot work in extreme dark environment. Dim light environment effects clearness of captured images and *Back-Mirror* may not work well or become less robust. Third, *Back-Mirror* requires extra accessory and back pattern to work.

To explore the feasibility of integrating patterns into the back position of rear-facing camera, we informally review the use of *Back-Mirror* in different smartphones, such as, Samsung Galaxy S2, Samsung Galaxy S3, and Samsung Note 2, and Asus Zenfone 2 Deluxe. Mirror and back pattern are attached on the smartphone backside, and smartphones with camera located at top middle position of the devices can perceive the back pattern clearly with proper adjustment on mirror angle.

6 Conclusion and Future Work

In this paper, we presented *Back-Mirror*, a camera-based approach for mobile interaction with BoD gestures. *Back-Mirror* detects tapping, swiping, and holding gestures using the built-in rear-facing camera with a small mirror reflecting images of a user's hand on smartphone backside in real time. We designed four applications to illustrate the feasibility and the potential of *Back-Mirror*. In the future, we are interested in conducting a complete user study to evaluate recognition accuracy of our *Back-Mirror* BoD gestures.

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