“Unfold and Go Touch”: A Portable Method for Making Existing Touchscreens Accessible to Blind and Low Vision People in Self-Service Terminals

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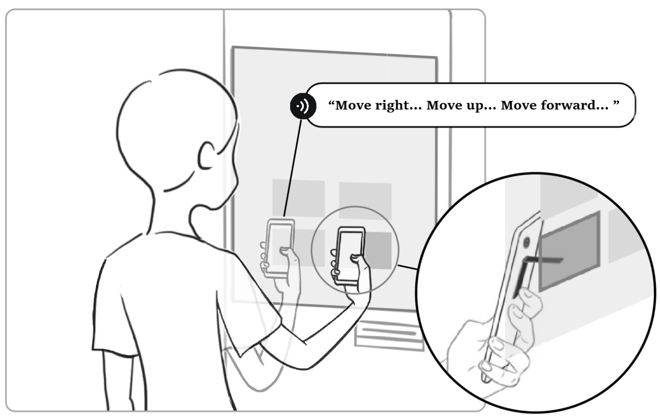

Figure 1: We proposed a voice-based interactive method using a conductive folding stand with the phone camera to allow BLV people to access both touchscreens of SSTs. User moves the phone close to the button according to the voice feedback and touch the button with the end of stand.

ABSTRACT

Self-service terminals (SSTs) are almost everywhere in our daily life and increasingly use capacitive and infrared touchscreens as the interface. Most of the current solutions to help blind and low vision (BLV) people access existing touchscreens mostly are only suitable for capacitive touchscreens and not for infrared touchscreens. In this paper, we proposed a voice-based interactive method using a conductive folding stand with the phone camera to allow BLV people to access both touchscreens of SSTs. Voice feedback was provided to guide users to move the phone close to the button and touch it with the end of the unfolded stand. Using a portable accessory, this method directly guided users to touch the target and effectively avoids false triggering. A preliminary evaluation indicated that our approach enabled users to access the target buttons on the touchscreen with high accuracy and a short completion time.

CCS CONCEPTS

• **Human-centered computing → Accessibility systems and tools**.

KEYWORDS

Non-visual interfaces, visually impaired users, accessibility, computer vision, mobile devices

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1 INTRODUCTION

Self-service terminals (SSTs) with touchscreens are widely popular and frequently used in our daily lives[10], such as supermarket self-checkouts, self-service ticket machines, and automated teller machines (ATMs). SSTs use different types of touchscreens, and increasing SSTs use infrared touchscreens instead of capacitive touchscreens as the interface because of their low cost, quick response, and scratch resistance[6]. However, blind and low vision (BLV) people cannot access existing different vision-based touchscreens easily[11]. The issue of BLV people accessing the touchscreens of various SSTs has received increasing attention. By introducing tangible interfaces, gesture language, or voice feedback, previous studies have explored how to make the touchscreen of SSTs accessible for BLV people [13, 19, 24]. These efforts implement specific software or hardware on SSTs allowing BLV users to interact with touch screens without relying on vision. They provide valuable guidelines for improving the accessibility of touchscreens, but generalizing these methods to all existing touchscreens of SSTs is difficult and costly.

There are approaches proposing accessories to help BLV people access existing touchscreens [4, 5, 14]. These methods are mainly designed for capacitive touchscreens and require constant contact with the screen to explore the target components on the interface. It was possible to avoid false triggering by insulating accessories on a capacitive touchscreen. However, unlike the capacitive touchscreen, the infrared touchscreen forms an infrared ray grid on the display surface. When the screen surface is touched, infrared rays are blocked, and the controller responds by recognizing the location of the touch through the blocked rays[18]. Touching the screen directly to explore the interface is highly likely to trigger other elements on the infrared touchscreen by mistake. Solutions to make existing infrared screens accessible have yet to be researched and proposed. Furthermore, SSTs are often used in public, so the portability of accessories is an important factor to be considered. Previous work relied on a range of customized components that need to be carried or worn separately (e.g., a ring worn on the user's fingertip[5], a plate that covers the touchscreen[14]), which made it challenging to access touchscreens efficiently in public places.

In this paper, we propose a more portable method for BLV people to access existing different touchscreens of SSTs. Through the camera and a conductive folding stand fixed on the back of a mobile phone, the user can browse elements on the touchscreen interface and find the button they need. And then, the user moves the phone close to the button according to the voice feedback and touches it with the unfolded stand (Fig. 1). This method directly guides the user to touch the target and effectively avoids false triggering, which is suitable for both capacitive and infrared touchscreens. All this system takes is a lightweight folding stand with an application on a mobile phone, which is highly portable. Using our method, we conducted a preliminary study in which blindfolded users touched different buttons at different locations and sizes. Our results show that this method can help users touch the target button on touchscreens with high accuracy and a short completion time without false triggering.

2 RELATED WORK

SSTs with touchscreens as the user interactive interface are becoming increasingly ubiquitous. Different types of touchscreens are applied to SSTs in different scenarios. In addition to the usual capacitive touchscreens, the infrared touchscreen is increasingly applied in outdoor SSTs because of their low cost, quick response, and scratch resistance[6]. SSTs with touchscreens are constantly being generalized, but their accessibility remains a burning issue[11, 20]. Touchscreens often lack tactile references and speech feedback, making them inaccessible to BLV people [26] and the adoption of different types of touchscreens also puts forward higher requirements for the accessibility of the touchscreens of SSTs.

Previous studies have explored how to make the touchscreen interface of SSTs accessible for BLV people. By introducing gesture language and voice feedback, Sandnes et al. implemented a prototype self-service ticket machine enabling blind users to select, undo and explore various options on touchscreens [24]. Different ways to browse and explore UI elements on large touchscreens, such as screen edge positioning, nearest item browsing, and speech feedback at path, also were proposed[13]. Physical input has been reintroduced into touchscreen interaction to provide more tactile feedback for BLV people, making touch screens accessible and contrasting with gesture interaction [11, 19]. Furthermore, several works [15, 19, 25, 26] investigated the accessibility of touchscreens and proposed some guidelines for future designers. However, these prior works primarily depended on specific hardware and software, while it remains unsolvable that many existing touchscreens cannot be modified and remain inaccessible for BLV users.

Some prior approaches proposed external accessories and applications to help BLV people access existing touchscreens. Shaun K. Kaneet al. have developed a series of transparent plastic plates that can be covered on the surface of touchscreens, which can help visually impaired people to locate target buttons on the interface to access the touchscreen through haptic feedback and a specific label of the plastic plate[14]. Anhong Guo et al. proposed VizLens, which sent interfaces inaccessible to multiple crowd workers to label and describe and uses computer vision to describe the UI element beneath the user's finger to help the visually impaired access multiple types of interfaces [4]. StateLens went beyond VizLens by providing a way to interactively generate touchscreen structures and let users access the interface with a set of 3D-printed accessories [5]. It should be noted that these accessories all need to touch the screen repeatedly to explore the interfaces. Because the touchscreens they studied were primarily capacitive, they could avoid false triggers with insulated accessories. However, the infrared touchscreen can be triggered once an opaque object touches the surface [18]. This means that the way proposed by previous methods that use an insulating tool to touch and explore the touchscreen is unsuitable for infrared touchscreens because they can easily lead to false triggering. Moreover, the accessories in the previous studies required to be carried or worn separately, which is not portable enough for BLV users.

To sum up, a more portable way for helping BLV people to access the existing different touchscreens in SSTs must be explored and proposed. Our method guided users to capture the full interface of the touchscreen through mobile phone cameras and voice prompts, preventing excess contact and false triggering on the infrared touchscreens. A normal conductive folding stand attached to the back of the phone acts as a touch accessory, enhancing the portability of the method.

3 OUR APPROACH

3.1 overview

The SSTs often adopt intuitive interfaces and simple operations so that users can reach the aimed service through simple selections [2]. Therefore, we set the main task of our approach to touch the aimed button, the most basic and common interaction behavior on the touchscreens of SSTs. We will explore how this approach deals with other operations in future work.

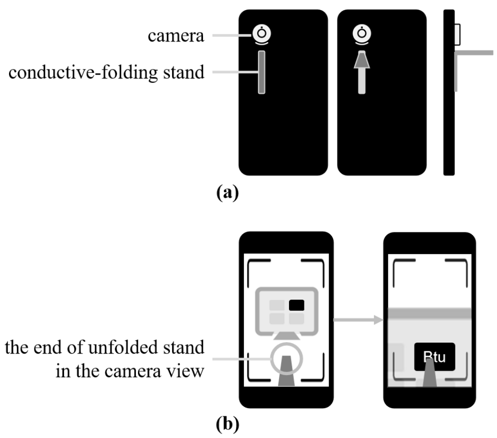

Figure 2: (a): A conductive-folding stand is pasted under the camera of the mobile phone; (b): The end of the stand will be within the range of the button captured by the phone camera when the button is triggered.

As shown in Fig. 2 (A), we fix a normal folding stand on the back of the phone below the camera. We attach the conductive material to the stand's surface to trigger the capacitive touchscreen. The end of the stand can be captured by the camera view when users are holding the phone, and the position of the target button could also be tracked by the phone camera (Fig. 2 (B)). Our method will automatically guide users to move phones to directly touch the button through the end of the unfolded stand. There is no other contact with the touchscreen, thus avoiding false triggering on the infrared screen. We implement an application on a mobile phone, and the entire pipeline of the system is presented in Fig. 3. The following subsections discuss each step in detail.

3.2 Capture and recognize the interface

When the BLV user comes to the touchscreen, he (she) can start the developed application on the phone. Similar to other blind photography [9], the user is prompted to unfold the stand and point the camera forward. Through the edge detection algorithm [23], the application guides the user to capture the full screen by spoken directions (i.e., moving up, down, left, or right) according to the real-time images captured by the camera. And then, the system will reverse engineering interface structures from full-screen photo[3, 16].

3.3 Select the on-screen target with *TalkBack*

After the segmentation and interpretation of the touchscreen interface, the GUI components on the touchscreen in the full touchscreen photo are extracted and transformed into the menu with *TalkBack*. *TalkBack* is the Google screen reader on Android devices and has been widely used by BLV users [22]. It enables users to navigate and activate items by non-visual interaction such as swipe and tap gestures[8]. With it, the BLV user can browse and select the target button they aim to trigger. By interpreting and transferring the touchscreen interface on the SST to the mobile phone, the user's exploration of the touchscreen is avoided, and the possibility of false triggering on the infrared touchscreen is eliminated.

3.4 Target tracking and move guidance

After obtaining the target button, the system will track its location in the camera view in real-time using the template matching algorithm [12]. The user is prompted to move the phone guided by voice so that the stand can approach and touch the target button. The voice feedback will be provided as spoken direction (up, down, left, right, forward, and back) every second, which is used in many existing approaches[7, 21] and usable without training [19]. One case of our strategy for guiding the user to move the phone is shown in Fig. 4. To avoid the frequent changes of directions, the user is first instructed to move the phone horizontally and vertically to make the end of the stand keep pointing toward the target button, then led to move forward to the screen. When the end of the stand diverges from the button range, the system guides the user to adjust horizontally and vertically to calibrate it back. In this way, the user could keep the end of the stand within the button range in the camera view while moving the phone close to the touchscreen to activate the target button.

The above strategy can be adapted to different terminal interfaces for BLV users to trigger buttons. Considering various scenarios with different SSTs and touchscreens, we also propose another guidance strategy for the small button (Fig. 5). This strategy presents a range called *activation range* in the camera view. It is the range of target button positions that ensures the stand can activate the target button when it touches the screen. With this range, while moving the phone, guiding the user always to keep the target button within the range can ensure the final triggering target button is successful. The *activation range* must be preset according to the specific interface and device. It is not as universal as the previous strategy but can reduce repeated correction because it provides more relaxed calibration conditions.

4 PRELIMINARY EVALUATION

Since this project was still in progress and some system functions had not been implemented, we conducted a preliminary user study on the part of guide interaction. The study aimed to 1) examine the approach's effectiveness when assisting BLV users in touching the target button and 2) understand the potential factors influencing how BLV users interact with the SSTs' touchscreens in practice.

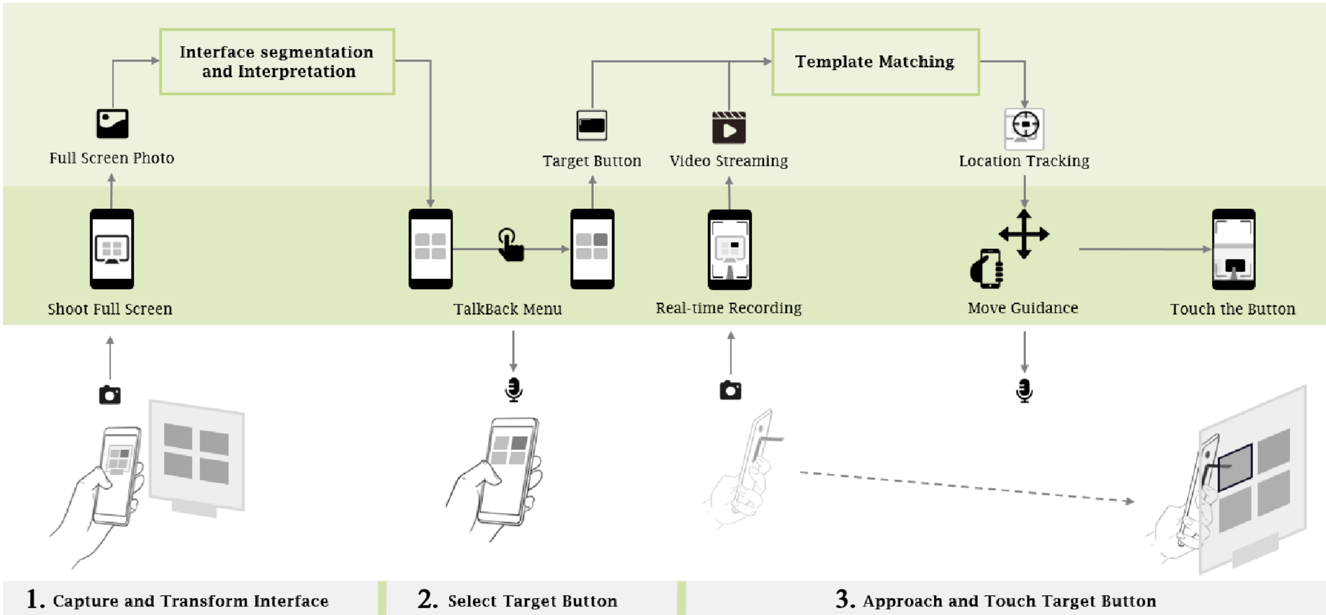

Figure 3: The pipeline of the system. BLV users can select the target button on mobile phones. The system tracks the button and provides spoken directions to guide users to move the phone. Finally, the target button will be touched by the end of the unfolded stand.

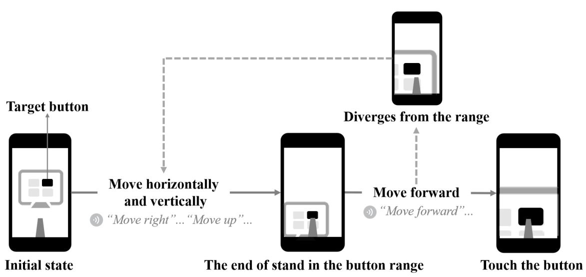

Figure 4: Guidance strategy of moving phone

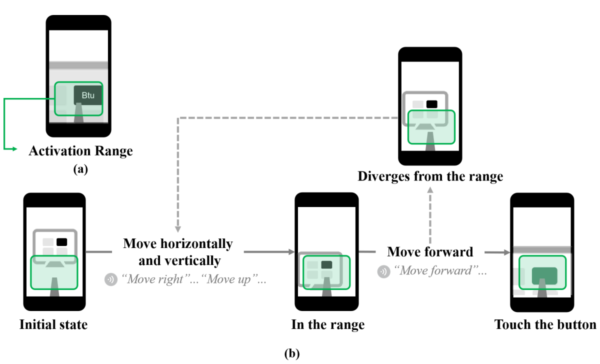

Figure 5: (a): Activation range: the range of target button positions that ensure the stand can activate the target button when it is touching the screen; (b): Guidance strategy with activation range

We chose a scenario referring to previous work [16], fetching packages from KuaiDiGui. The KuaiDiGui, as one kind of SSTs with infrared touchscreens, is a popular type of self-service package pickup machine for people's daily lives. In 2020, more than 770,000 KuaiDiGui were used in China, an increase of 36,600 over 2019, a yearly accumulation of 90.15 percent [17]. However, BLV users have suffered particular challenges in operating the touchscreens of KuaiDiGui [16]. As shown in Fig. 6, we selected the two most commonly used buttons and the smallest button on KuaiDiGui's interface as the target buttons to explore how our approach performs when touching these buttons.

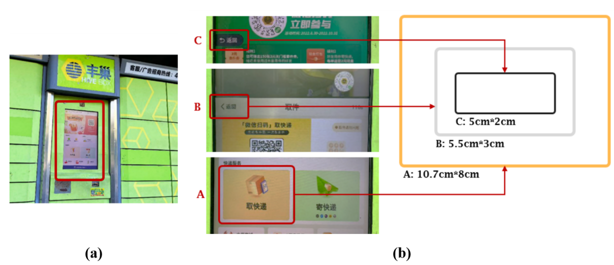

Figure 6: (a): The touchscreen interface of KuaiDiGui; (b): Target buttons selected from the KuaiDiGui interface with their number and dimensions.

4.1 Apparatus and Participants

The system implemented target button tracking and voice guidance installed on a mobile phone. The folding stand is *5cm* long and is attached to the back of the phone and *2cm* below the camera (Fig. 7). We built a prototype on a pad to display the target button at its actual size and record the coordinate position of the touch point when the screen is touched. The pad can be placed at different positions on the vertical whiteboard to simulate the touchscreen area of SST.

The BLV participant's recruitment was affected due to COVID-19. Therefore, we recruited 10 sighted participants (5 female, 5 male, age 20-40) to participate in the experiment blindfolded (Fig. 7) similar to previous work [1, 19]. We plan to recruit more BLV people for the full and final evaluation.

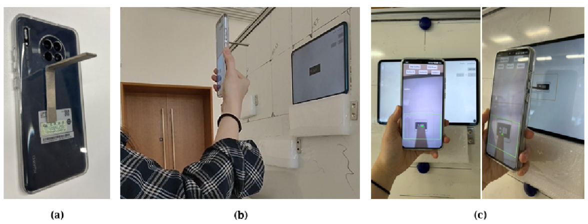

Figure 7: (a): The phone with our system installed; (b): Participant moving the phone according to the verbal feedback. (c): The stand touched the target button on the simulated screen.

4.2 Procedure

Participants used our system to touch the target button in five different locations (top left, bottom left, top right, bottom right, and middle) on the simulation screen of KuaiDiGui. For each button placement, participants completed three trials. Following a brief introduction, participants had three minutes to practice using the application. Then, the researcher guided the user to the simulated touchscreen and assisted them in lifting the phone to a position that could capture the full screen. After that, the application began to track the target button and give voice instructions to guide the users to move the phone. We take the text on the button as the tracking target of the algorithm and judge whether the button can be activated by whether the touch point falls in the button ranges. We recorded the task duration and user performance (i.e., whether to activate the button successfully) with each trial, with the coordinated position of the touch points and the corresponding button placement.

4.3 Results

We summarize our user study results and user feedback in this subsection. Regardless, the data collected provided great encouragement for our follow-up work. The result of participants' touch accuracy is shown in Fig. 8. All participants in the experiment can touch button A ($AVG = 100\%, SD = 0$) accurately in each trial, and the average accuracy of button B is 93% ($SD = 0.083$) which is also an ideal value. As the smallest one, the touch accuracy of button C is lower than that of the other two buttons, and the data difference between different users is significant ($AVG = 77\%, SD = 0.19$). We recorded 150 touching positions of ten participants in 15 trials. The distribution of all touch points on the screen, and the range of three buttons are shown in Fig. 8.

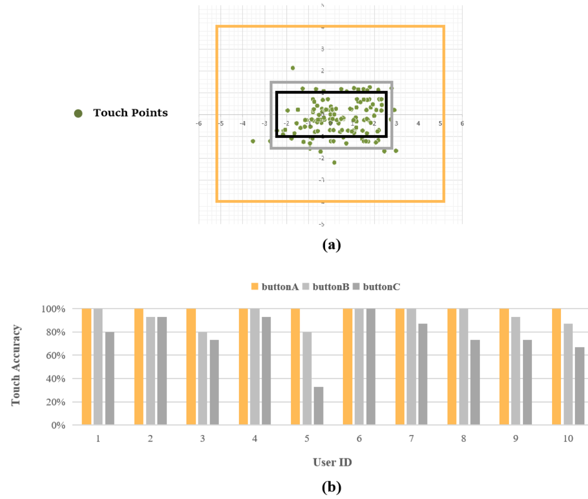

Figure 8: (a): Distribution of all touch points on the touchscreen; (b): Touch accuracy of different users and buttons.

As shown in Fig. 9, we examined the duration participants needed in the moving process. The movement started just where the phone's camera is able to capture the full screen and ends when the stand touches the screen. Each user completed a touch in less than one minute, and the average completion time was 34.26 seconds. In addition, we measured the average time spent by ten users touching buttons in different locations (Fig. 9). When the button was placed in the center of the interface, the completion time was significantly shorter than that when the button was placed in the corner. The specific orientation of the button in the corner of the interface has no obvious effect on the completion time.

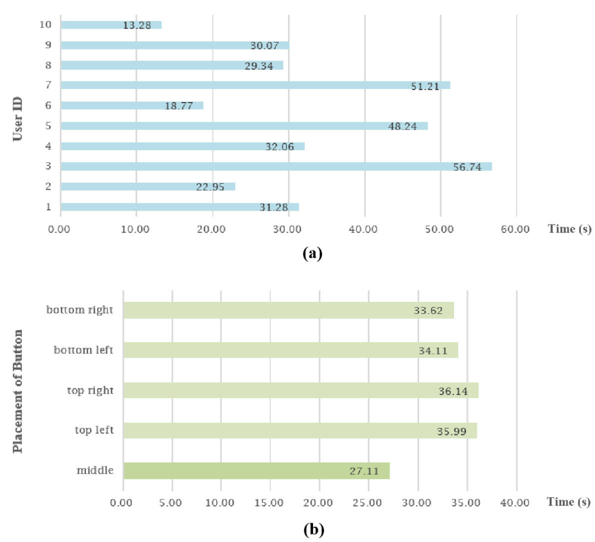

Figure 9: (a): Average completion time of each participant; (b): Average completion time of each placement of button.

5 DISCUSSION AND FUTURE WORK

Using our method, we find a high probability that users can touch the most commonly used buttons on KuaiDiGui. This indicates that touch accuracy is affected by the button size, and how to help users touch small buttons more accurately will be our next exploration. In addition, we find that all of the subjects' contacts fell within $7cm$*$5cm$ around the calibration center, and 98% of the contacts fell within $6cm$*$4cm$. This distribution trend and data may provide a reference for the button size design of the SST interface and other researchers. The waiting time for the KuaiDiGui is 120 seconds. The main page will automatically return if no input is entered for more than 120 seconds. The average completion time of our method is 34.26 seconds, much less than 120 seconds. This means that our approach can adapt to the waiting time set by KuaiDiGui. However, participants took longer to touch the corner button of the interface than the center button. Whenever the target is close to the center of the camera's view, the moving path will be shorter, which should explain this difference.

Because this is an ongoing project, the results are preliminary and cannot be considered conclusive. There are several limitations, such as the simulated BLV participants and the small number of participants due to COVID-19. The proposed interface transformation and target button selection with TalkBack will be implemented in the future, along with developing a complete interaction process. A further evaluation will be conducted with BLV people on both infrared and capacitive touchscreens. Pure voice feedback is not necessarily the most efficient form to prompt BLV users to move. We will study the effects of other modalities of feedback (such as vibration, spatial sound, sonification, etc.) to find the best possible form of feedback. We will also investigate how to guide the user back to the original page once a false trigger occurs during the user interaction process and how to guide the user to adjust the phone to the appropriate position. In addition, more types of SSTs and touchscreen interfaces will be considered and investigated.

6 CONCLUSION

SSTs increasingly use different touchscreens as the interface. Current solutions to help BLV people access existing touchscreens are mostly suitable for capacitive touchscreens but inevitably cause false triggering on infrared touchscreens. In this paper, we proposed a portable method for BLV people to access existing capacitive and infrared touchscreens of SSTs, combining the camera with a folding stand of a mobile phone. We have conducted a preliminary user experiment on target button tracking and voice guidance. The results demonstrated the feasibility of our approach in helping BLV people to touch the touchscreen button. In the future, we will continue to refine and optimize the method and conduct a full evaluation.

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