

Investigating On-Screen Gamepad Designs for Smartphone-Controlled Video Games

MATTHIAS BALDAUF, Vienna University of Technology

PETER FRÖHLICH, AIT Austrian Institute of Technology

FLORENCE ADEGEYE and STEFAN SUETTE, FTW Telecommunications

Research Center Vienna

On-screen gamepads are increasingly used as controllers for video games on distant screens, yet lack the typical tactile feedback known from hardware controllers. We conducted a comparative lab study to investigate four smartphone gamepads inspired by traditional game controllers and mobile game controls (directional buttons, directional pad, floating joystick, tilt control). The study consisted of both completing a formal control test as well as controlling two popular video games of different genres (*Pac-Man* and *Super Mario Bros.*). The results indicate that the directional buttons require the most attention of the user, however, work precisely for direction-restricted navigational tasks. Directional pad and joystick showed a similar performance, yet they encourage drifting and unintended operations when the user is focused on the remote screen. While currently unfamiliar to many users, the floating joystick can reduce the glances at the device. Tilt turned out to be not sufficiently precise and quick for the investigated tasks. The article concludes with derived design guidelines with easily realizable measures for typical contexts such as casual gaming at home or spontaneous gaming on public displays.

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1. INTRODUCTION

Due to their wide penetration and manifold technical capabilities, smartphones have evolved to universal remote controls over the last few years. Ubiquitous wireless connectivity and modern input modalities such as high-resolution touchscreens and voice recognition have enabled a broad range of mobile applications for controlling remote desktop computers, home automation systems and home cinemas. One of the most recent and popular use cases is utilizing a touchscreen smartphone as a game controller

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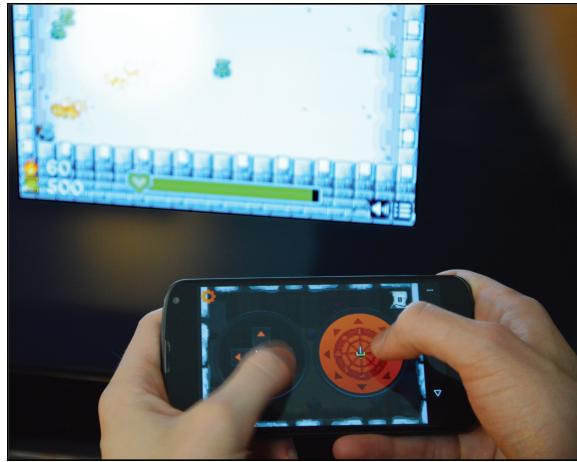


Fig. 1. *Brass Monkey®* is a recent example for utilizing smartphones to control video games through on-screen gamepads.

for a video game on a distant large screen. Respective applications are aimed at the growing number of casual gamers who play free Web games or emulated console games on their home computers but do not own a hardware controller. Further they can be used for increasingly deployed interactive public displays which offer (multiplayer) games for marketing purposes. Current publicly available controller apps with so-called on-screen (or soft) gamepads include *Ultimate Gamepad*,¹ *Mobile Gamepad*,² or *GestureWorks Gameplay Remote*³ as well as frameworks for developing custom games and gamepads like *Brass Monkey*⁴ (Figure 1). Overall, only these mentioned apps account for several hundred thousand downloads from respective application stores.

Using a touchscreen smartphone for controlling a video game on a remote screen has several peculiarities compared to a traditional hardware controller or the control of a mobile game. The most obvious one is the lack of tactile feedback: hardware controllers feature protruding physical knobs and buttons that facilitates their usage without looking at them. This focus on the remote screen also distinguishes this use case from controlling mobile games. When the actual game and the corresponding control elements are presented on the same touch display, only minor gaze changes are required to keep them in view or the control elements might be even recognized from the corner of an eye. In contrast, when the smartphone is purely used as controller, longer gaze switches away from the game screen can easily lead to gameplay mistakes.

While an extensive body of research on input devices and mobile game controls exists, there is almost no scientifically validated knowledge about the optimal design and application of touchscreen smartphone controls for the aforementioned use case of casual gaming at home and spontaneous gaming on public displays. To explore the general characteristics of potential touchscreen gamepads as well as to assess their concrete suitability for specific game genres, we conducted a comprehensive comparative lab study. We selected four gamepad designs for touchscreen smartphones (Figure 2), which are either counterparts of established hardware controllers or have proven

¹<https://play.google.com/store/apps/details?id=com.negusoft.ugamepad>.

²<https://play.google.com/store/apps/details?id=com.mmh.mobilegamepad>.

³<https://play.google.com/store/apps/details?id=com.ideum.gpcontroller>.

⁴<http://playbrassmonkey.com/>.

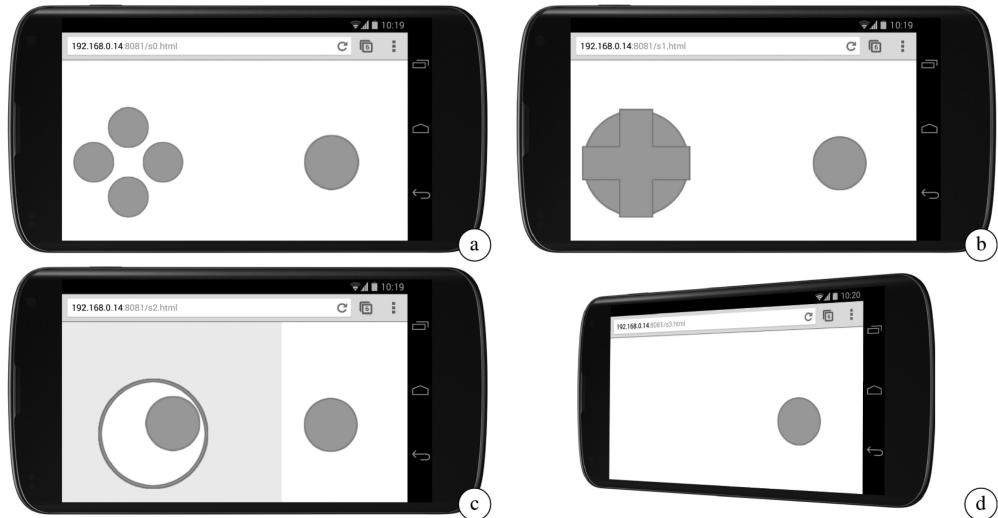


Fig. 2. We compared four different gamepad designs for touchscreen smartphones: directional buttons (a), a 8-way d-pad supporting swiping (b), a virtual joystick (c), and a gestural tilt control (d).

suitable for mobile games, and tested them in a formal control test and in two popular games: the arcade game Pac-Man and the platform game Super Mario Bros.

The first gamepad features *directional buttons* (Figure 2(a)) and represents the touchscreen version of haptic navigation buttons used by the early Nintendo Game & Watch series, for example. The motion control consists of circular buttons placed in the traditional cross arrangement and supports the four main directions. The second gamepad, the *directional pad* (Figure 2(b)), or *d-pad* for short, resembles the appearance of modern video game console controllers with a touch-sensitive eight-directional control (i.e., four main directions plus four diagonals). Such controllers are typically applied for mobile platform games as semi-transparent overlays.

The *virtual joystick* (Figure 2(c)) is the touchscreen counterpart of the well-known input device. It features a movable knob which can be dragged to specify a direction. Several popular recent mobile games such as *Terraria*⁵ make use of this novel control. The fourth gamepad in our study is the *tilt control* (Figure 2(d)). Similar to motion-sensitive game consoles like the Nintendo Wii or successful tilt-based mobile games like *Doodle Jump*,⁶ this gamepad exploits the device orientation for determining the desired direction.

In the remainder of this article, we present a detailed description of the study. We introduce our research hypotheses, explain the experimental setup, and present the results. Finally, we derive concrete recommendations for the design and implementation of smartphone gamepads for such large screen setups.

2. RELATED WORK

The work presented in this article touches upon several research disciplines. In the following, we outline related previous research and developments in the fields of handheld interaction with large displays, controlling handheld video games, and evaluating game controllers in general.

⁵<https://play.google.com/store/apps/details?id=com.and.games505.TerrariaPaid>.

⁶<https://play.google.com/store/apps/details?id=com.lima.doodlejump>.

2.1. Handheld Interaction with Large Displays

Over the last few years, smartphones have been intensively investigated for controlling applications on large displays, either in home settings or in public environments. In their design space, Ballagas et al. [2006] distinguish between supported tasks (such as positioning and orientation) and interaction styles (such as continuous and discrete positioning). Boring et al. [2009] compared three techniques for a non-touchscreen phone (pressing keys, tilting and moving the device) for a continuous positioning task and found that the motion-based techniques allow fast selection times but suffer from more errors than the simple key approach. Baldauf et al. [2013] evaluated techniques for touchscreen smartphones and found that direct visual approaches like a miniature view of the remote screen are superior to the alternatives.

Related interaction techniques have been realized and tested for a variety of gaming and entertainment scenarios. For example, *Wordster* [Luoju et al. 2013] is a multi-player word finding game for public displays. Orientation-aware handheld controllers were proposed for playing a racing game on a remote screen by tilting the smartphone [Vajk et al. 2008], for rotating 3d models [Katzakis and Hori 2010], or for controlling jigsaw puzzles on a wall-sized projection [Cao et al. 2008].

The *MobiLenin* system [Scheible and Ojala 2005] uses a mobile application to enable visitors of a pub to vote for music videos to be played on a public display. Lorenz and Jentsch [2010] introduced an ambient media player controlled through a mobile phone. The related *Augmented Video Wall* [Baldauf and Fröhlich 2013] allows passers-by to start movies on a large public display through their smartphones and supports concurrent viewing by means of augmented reality. Advanced smartphone controls beyond stroking and tilting gestures have also been investigated for media façades, for instance, a camera-based approach for collaboratively solving puzzle games [Boring et al. 2011] or exploiting the player’s position around the building for gaming purposes [Böhmer et al. 2011].

So far, Joselli et al. [2012] presented the only work investigating a touchscreen smartphone as a replacement for a traditional game controller. They compared the performance of soft keys and tilt control for a 2d space shooter on a remote display. However, they did not explore advanced touchscreen controls, nor did their preliminary evaluation with four participants yield any distinct results. One of the scarce studies investigating the impact of gaze switches in multidisplay environments was presented by Rashid et al. [2012]. In their study, the participants performed map, text, and photo search tasks with a smartphone and a large display under three different conditions (mobile only, input on smartphone and output on large display, input on smartphone and output on both smartphone and large display). The results indicate that mobile-controlled large displays are generally the best option across the investigated tasks.

2.2. Controlling Handheld Video Games

Handheld video gaming has a history of more than three decades. Early mobile gaming consoles like the Game & Watch series by Nintendo featured a number of physical buttons for user input at both sides of the displays. The consoles were held with two hands in landscape mode and operated with the thumbs. Typically, the motion control in form of four buttons or a 4-way directional pad for the main directions was placed on the left side, buttons for triggering game actions like shooting on the right side. This basic arrangement did not change in related subsequent devices such as several generations of the Nintendo Gameboy or the PlayStation Portable by Sony. When first simple games became available on feature phones, hardware keys—in this case the numerical keypad—were the input method of choice too. For example, players could change the course of the character in the popular Snake game by pressing the 2, 4,

6, and 8 key for the corresponding direction. Early smartphones started to enable first orientation-aware controls through their built-in accelerometers, for instance, for games of skill where users navigate a ball through a maze.

Today's smartphones mainly feature touch-sensitive screens instead of former hardware keys and thus button-based controlling concepts needed to be revised. For example, simple stroke gestures have been proven efficient and easy-to-learn in the successful game Angry Birds. More traditional games apply the typical gamepad design with a d-pad and action buttons by superimposing semi-transparent touch controls on the left and on the right side of the screen – hazarding occlusions of the actual game content. "Virtual joysticks" are another port from stationary gaming consoles. In contrast to a "digital" d-pad, they allow for intermediate values according to the amplitude. An alternative to the typical implementation with the draggable knob centered around a fixed screen location, recent mobile games (e.g., Terraria) feature a "floating joystick". This version does not rely on absolute touch-sensitive screen areas but works relatively to the first touch point: when the user puts his finger onto (the usually left half of) the display, the joystick with its knob appears just below, can then be dragged relatively to this joystick center and disappears when the user lifts up the finger.

With the growing popularity of smartphones as mobile gaming platforms, several hardware accessories and even dedicated gaming smartphones have been brought out to improve the gaming experience. For example, the Xperia Play device by Sony Ericsson is a slider smartphone with both a touchscreen and game controls like a haptic d-pad and several buttons. Examples for respective accessories include the Logitech Powershell⁷ and controllers by Moga⁸ which extend a smartphone with physical buttons or the touchscreen gaming controls by steelseries⁹ or Ten One Design¹⁰ which can be directly placed onto the touchscreen for tactile feedback. However, typical casual gamers do not own such gadgets, neither are they available on-the-go for the targeted public display use case.

2.3. Evaluating Game Controllers

A formal evaluation procedure suitable for game controllers is described in the ISO 9241-9 standard for nonkeyboard input devices [Brown et al. 2010; Douglas et al. 1999]. It proposes a standardized methodology based on the well-known Fitts' index of performance [Fitts 1954]. From the six defined tasks, the multidirectional tapping task, which includes a series of differently sized and positioned targets, describes best the typical moving and selecting tasks in 2d games and has been used in a number of related studies [Baldauf et al. 2013; Boring et al. 2009; Douglas et al. 1999; Natapov et al. 2009]. Alternatively, researchers have been studying the performance of gaming controls directly with existing video games by comparing spent lives, achieved scores, etc. [Chehimi and Coulton 2008; Medryk and MacKenzie 2013; Wong et al. 2010; Zaman and MacKenzie 2013]. While respective results are of concrete practical value, they are obviously restricted to a specific game (genre).

A major focus in previous research on controls for mobile games has been put on the comparison of soft and hard keys [Chu et al. 2013; Chu and Wong 2011; Lee and Zhai 2009; Oshita and Ishikawa 2012; Wong et al. 2010; Zaman et al. 2010]. The key result of substantially all the studies is that physical buttons outperform touchscreen controls or are better perceived by the participants. In addition, Wong et al. [2010] report that for the simple block filling game 8 out of 12 participants scored higher

⁷<http://gaming.logitech.com/en-us/product/powershell-controller-and-battery>.

⁸<http://www.mogaanywhere.com/>.

⁹<http://steelseries.com/us/products/other/steelseries-free-touchscreen-gaming-controls>.

¹⁰<https://tenonedesign.com/fling.php>.

with touchscreen keys, however, 10 participants stated to prefer hard keys. Zaman and MacKenzie [2013] proved the preference for physical buttons over soft buttons also for tactile accessory buttons for a “run-and-gun” game.

Chehimi and Coulton [2008] and Gilbertson et al. [2008] tested tilt-controlled 3d games in first and third person perspective. The participants found this control easier than using the hardware joy pad and scored higher than with a hardware keypad, respectively. Studies investigating tilt-based 2d games include the work by Browne and Anand [2012] who report of both objective and subjective advantages over touchscreen buttons and swiping gestures for a space shooter. For a *Pong*-like game with a movable paddle, Medryk and MacKenzie [2013] recorded higher game scores for soft buttons but better subjective ratings for tilt which was described as more challenging and engaging. Especially targeted at visually impaired people, Valente et al. [2009] combined a tilt control with an “audio radar” in a custom-developed mobile game and found it well received by participants, yet did not compare it to any alternatives.

A joystick-like touch control was part of a preliminary study on mobile motion controls by Lubitz and Krause [2012]. The researchers compared multitouch input (the display was separated in six areas for corresponding movements), so-called one-finger input (a basic floating joystick detecting directional swipes), and tilt-based control for a 2d platform game. The participants’ feedback was negative for both multitouch and tilt control. Hürst and Nunez [2013] compared an on-screen joystick with directly touching the target location and tilt-based control for navigation in 2d and 3d worlds, however, could not find clear evidence for any preferences.

3. METHOD

In the following, we describe the design and setup of the comparative lab study as well as our research hypotheses.

3.1. Software Framework

For building functional study prototypes of the gamepads to be evaluated, we used our custom-developed open-source framework *ATREUS*.¹¹ *ATREUS* does not rely on a native mobile application like related aforementioned projects but enables purely Web-based remote controls executed in a mobile browser. While there have been early attempts towards such Web-based smartphone controllers (e.g., by Google with its “Chrome Experiments”¹²), *ATREUS* represents the first respective comprehensive research framework. The core components of *ATREUS* comprise a server application and a mobile library exchanging control commands (e.g., whether a button has been pressed or released) over a Websocket connection.

3.2. Game Controllers

Using the *ATREUS* framework, we realized the four previously introduced game controllers. Our emphasis in this study was on the navigational controls, thus we integrated only one action button of equal size and position on each gamepad. Related to typical hardware controllers, this action button was placed on the right side, while any navigational controls were located on the left. As depicted in Figure 2, we deliberately applied a very reduced screen design with subtle colors to focus the subjects’ attention to the actual controlling concept, not any visual features. All gamepads are designed to be held with both hands in landscape mode as depicted in Figure 3.

¹¹<http://atreus.ftw.at>.

¹²<https://chrome.com/campaigns/rollit>.



Fig. 3. A participant controlling the Super Mario Bros. game with the joystick technique.

3.2.1. Directional Buttons. This gamepad (Figure 2(a)) features four circular navigation buttons placed in the traditional cross pattern plus the action button on the right side. Like its hardware prototype in the Nintendo’s Game & Watch series the directional buttons are a little bit smaller than the action button to allow for a more compact arrangement. Pressing a button sends the corresponding movement command, leaving the button area or raising the finger stops the respective movement. As a clone of the mentioned hardware version, our directional buttons need to be actively pressed, that is, sliding the finger from one button to another is not supported.

3.2.2. Directional Pad. Our soft d-pad (Figure 2(b)) features an eight-directional control (i.e., four main directions plus four diagonals) and, like its hardware counterpart, sends pressed/released events for each direction but does not support intermediate values. The d-pad’s touch-sensitive areas are pie slices of 120 degrees range around the main directions while the overlapping areas trigger the corresponding diagonal commands. In analogy to the hardware version and implementations for mobile games, our realization supports sliding the finger over the d-pad, for instance, it is possible to drag the finger directly from left to right to change the direction of the game character accordingly. Raising the finger or moving the finger beyond the area of the d-pad sends a release command.

3.2.3. Joystick. The joystick is a “floating” version (Figure 2(c)), that is, the joystick does not rely on absolute touch-sensitive screen areas but works relatively to the first touch point: when the user puts his finger onto the lightgrey area, the joystick with its knob and a circular border appears around the touch point. Now the user may drag the knob relatively to the joystick center to send directional commands (for example, Figure 2(c) depicts a movement to the right). The joystick uses the same configuration like the d-pad (120 degrees range for main directions plus diagonals) but movement commands are not cancelled when the finger leaves the circular joystick area. Further, like in many mobile games with a semi-transparent on-screen joystick control, our joystick supports two sensitivity levels: dragging the knob more than 25% of the border radius away from the center starts a movement with half the speed, dragging the knob to the border and beyond starts a “normal” movement (like the buttons and the d-pad). When the user raises the finger, any movements are stopped and the joystick disappears.

3.2.4. Tilt Controller. In this gestural approach (Figure 2(d)) tilting the device to the left corresponds to pressing a “left” button, tilting the device towards the body corresponds to pressing an “up” button, etc. In pretests, we determined a device orientation of 30 degrees tilted towards the user’s face (typical device position when reading in landscape mode) as the neutral position. A pitch of five degrees or more from this position to the left or right triggered a horizontal movement command, a roll of 14 degrees forward or backward a vertical movement. Also the tilt control supports an intermediate value: within the first three degrees beyond these thresholds a slow movement is started, more sweeping tilts trigger the default movement speed. Bringing the device back into the neutral position or into another position stopped the previous movement command.

3.3. Research Hypotheses

Based on the literature review and own experiences with aforementioned publicly available apps, we constructed research hypotheses for each gamepad, one with regard to the formal control test (a) and one concerning the gamepad’s expected suitability for a concrete video game (b). Some of these hypotheses were deliberately oriented towards benefits and constraints of the gamepads, which each could materialize within different measures. We follow this high-level approach (resulting in 2x4 hypotheses), as multiplying hypotheses for each measure would provide no benefit for methodological sharpness, but would hamper the readability of the article.

Directional Buttons. *H1a.* We expect the gamepad with directional buttons to require the most attention since it only allows for discrete button presses and does not support swiping gestures.

H1b. We assume that the directional buttons (together with the similar d-pad) are best suited for the swift navigational commands in Pac-Man.

Directional Pad. *H2a.* Due to its familiarity and the ability for diagonal movements, we assume that the 8-way directional pad outperforms the other techniques in terms of completion time.

H2b. Since the original gaming console used a d-pad as well, we expect the participants will subjectively prefer the d-pad for Super Mario Bros.

Joystick. *H3a.* We expect the Joystick technique to be more accurate than alternatives due to its touch-based sensitive approach.

H3b. Because the Joystick supports directional commands without looking at it through swiping gestures, we expect that the participants will achieve the best objective game performance for Super Mario with this gamepad.

Tilt Control. *H4a.* According to related research, we expect the tilt control to have the lowest accuracy of all gamepads.

H4b. We assume that for Pac-Man users score fewest points with the tilt control, since we assume its gestural approach less suitable for quickly controlling the game character.

3.4. Experiment Setup

We conducted the experiment in the user experience lab of our institute. The lab was arranged similar to a living room with a Sony flat screen TV and a couch at a distance of two meters (see Figure 3). The screen with a screen diagonal of 46 inch (117 cm) and a resolution of 1920×1080 pixels was connected to a laptop computer running the ATREUS framework. The framework was configured to start and stop existing console games by using an emulator software and control the games by triggering respective

key events. While the large screen presented the respective test applications, the laptop display showed the test manager a custom operator console for setting the appropriate study conditions such as the current gamepad or application to be controlled. The test manager sat at table beside the test setup in order to introduce the tasks and gamepads, to observe the participants' facial expressions and gazes, and to answer issues concerning the questionnaire. During the setup of the study environment, we paid particular attention to find a suitable location for the test manager's desk and chair from where accurate observations of the participants' gazes were possible. In our pretests, we found this manual recording very reliable and efficient for recognizing and counting the expansive gaze changes between the large screen and the mobile display.

As mobile device we used an LG Nexus 4 powered by Android. The smartphone was connected to the laptop computer over a 802.11n Wifi. For easily switching between the different gamepads, we used an NFC (Near-Field Communication) tag: after a participant had completed a task and returned the device, the test manager set the next test configuration through the study console and then simply touched the tag with the smartphone to start up the appropriate gamepad (i.e., open the corresponding Web page).

3.5. Participants

We invited 30 participants to take part in our user study. The participants were recruited via public announcements and the institute's test person database. 15 male and 15 female were tested, aged between 19 and 50 years (mean = 31.4, median = 30.0). As remuneration, each participant received a voucher for either a grocery store or consumer electronics store.

4 participants were left- and 26 right-handed, 19 participants owned a smartphone or a tablet (9 both, 2 none). On average, they rated their expertise on using a touchscreen with 2.1 on a five-point Likert scale (1 = very good, 5 = very bad). We deliberately recruited participants with interest in video games and respective experience with various games and controllers: each of them stated to play video games more than once a month, 17 more than once a week. 20 participants stated to play mobile games on their smartphones, ten participants play only on their stationary gaming consoles and computers.

3.6. Study Design and Tasks

We designed our study as a within-subject experiment, that is, after completing a short demographic questionnaire, each participant used each controller to perform several test tasks. In contrast to prior work which either applied a formal control test or used real-world applications to assess the performance of new input techniques, we aimed at investigating both the general characteristics of a gamepad design as well as its suitability for specific game categories and thus combined the two evaluation approaches. Each test consisted of two major phases (Table I), the formal control test and the gaming phase, and closed with a final interview. For both phases, the order of the gamepads was systematically varied in order to avoid any learning and preference effects.

3.6.1. Formal Control Test. In contrast to prior work, we aimed not only at investigating the gamepads for specific games but also at gaining knowledge about their general suitability for a very common game task, namely controlling a character in a 2d (or 2.5d) environment in top-down perspective (e.g., in role play games, strategy games, board games, racing games). Due to the similarity to traditional pointing tasks (precisely moving and placing a remote element), we based this first study task on the aforementioned multidimensional tapping test being part of the ISO 9241-9 standard for

Table I.

Each participant used each gamepad (in varied orders) in a structured formal control test and for controlling two popular video games on the remote display.

Gamepad	Task Type	Trials
Directional Buttons	Formal Control Test	2 blocks x 2 sizes x 2 dist. x 8 orient.
Directional Pad		
Joystick		
Tilt		
Directional Buttons	Pacman	3 lives
	Super Mario	1st level
Directional Pad	Pacman	3 lives
	Super Mario	1st level
Joystick	Pacman	3 lives
	Super Mario	1st level
Tilt	Pacman	3 lives
	Super Mario	1st level

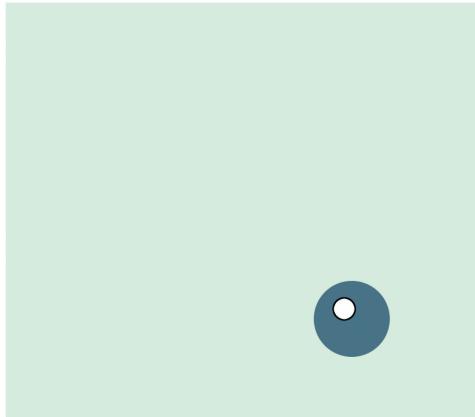


Fig. 4. The first task in our study was a formal control test based on the ISO 9241-9 standard for evaluating nonkeyboard input devices. Participants had to move the abstract white game character as quickly and precise as possible over the center of appearing circular target areas with varying size, distance, and orientation.

evaluating nonkeyboard input devices. This test has proven suitable and informative for assessing novel input methods in numerous related studies [Baldauf et al. 2013; Boring et al. 2009; Douglas et al. 1999; Natapov et al. 2009].

The participants used each of the four gamepads to complete two blocks of control tasks. Each block consisted of 32 trials. Before each trial, a white circle, the abstract game character, was placed over a centered “start” button and the participant actively started the trial by hitting the action button. The goal of each trial was to move the white circle over the center of a blue destination item of varying size and distance and confirm the position by hitting the action button (Figure 4). In contrast to traditional pointing devices like a mouse, the movement of the circle was nonweighted but linear to resemble a basic 2d game. The distinct trials consisted of two destination sizes (40 and 80 pixels), two distances (150 and 320 pixels), and eight orientations (0 to 315 in intervals of 45) with regard to the screen center and were presented to the participants in randomized order. Between the first and the second test block we had a short break of a few seconds.

When using a new gamepad, the participants could complete some trials in a training mode until they felt comfortable (as suggested in the standard). The test manager instructed the participants to solve the task as fast and accurately as possible. For each trial, we logged the completion time (duration between start and confirmation), accuracy (the difference between the two circle centers) as well as potential errors (i.e., the action button was pressed but the center of the white circle was not within the blue destination). Further, the test manager recorded the number of gazes at the gamepad during the test. After the participants had completed both blocks with a gamepad, the test manager asked them to rate several questions on a five-point Likert scale. We used an established questionnaire for assessing input devices [Douglas et al. 1999] with questions regarding the perceived task performance, mental effort, physical effort, usage difficulty, learning effort, accuracy, speed, comfort and fun. We added one specific question addressing the perceived ability to use a gamepad without looking at it.

3.6.2. Gaming. In the second phase of the study, the participants were asked to control two well-known video games. We selected the following two games due to their simplicity and popularity (for example, the training phase was reduced since all of the participants knew and had played the games before) and because they represent two game categories with different control patterns. Please note, that in contrast to the former control test, these games did not support the intermediate values of the joystick and the tilt control but only digital (pressed/released) commands. Before the actual tests, we conducted short training phases where participants could gain some experience with the games and the current gamepad and were also told about beneficial in-game behaviors.

Pac-Man. In this arcade game of skill, the player controls the circular yellow character Pac-Man through a maze with the goal of “eating” all dots (Figure 5). The maze is also populated by “ghosts” which need to be avoided - in case of a collision the player loses one of his three lives. The Pac-Man moves by itself, however, the player controls the course by issuing a direction command at a junction or in a corner. After a short training phase, the participants were instructed to spend the three lives and complete the first maze. When the participants had solved the task or spent all lives, the test manager wrote down the achieved score.

Super Mario Bros. Super Mario is a typical side-scrolling platform game where players can move the protagonist to the left and the right and make him jump to overcome chasms, avoid enemies, and scale higher platforms (Figure 6). The goal of the game is to reach a flag at the end of each level. Again, participants were allowed a training phase when they started to use a new gamepad. Having gained experience with the controller and the game, they were instructed to complete the first level of the game. Since we used a cheat for the game, the participants could use as many lives as they wanted and could cancel the task when they had lost interest. For this game, the test manager noted whether the participant had completed the level and how many lives were spent.

3.6.3. Final Interview. After the participants had gained extensive experience with each of the gamepad designs throughout the two interactive study phases, the test manager conducted a final interview. Here, the participants were asked to rank the gamepad techniques with regard to their preference for the two games. Furthermore, subjective experiences were elicited within a qualitative interview. Overall, the entire test procedure took about two hours per participant.

4. RESULTS

Overall, we logged more than 256,000 issued commands throughout the study. For each task type and measure, we ran a general linear model repeated measures analysis of

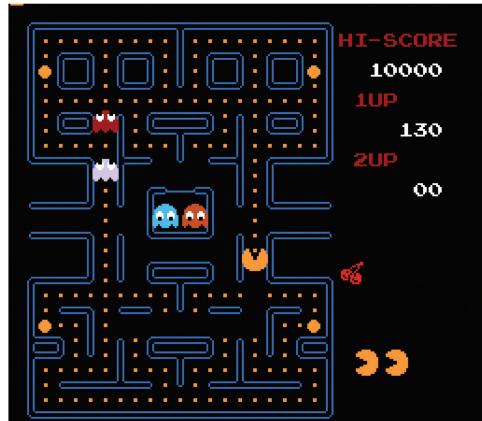


Fig. 5. The second study task included the well-known game Pac-Man where a game character must be navigated through a maze to “eat” all dots. When hitting a ghost character, the player loses a life.

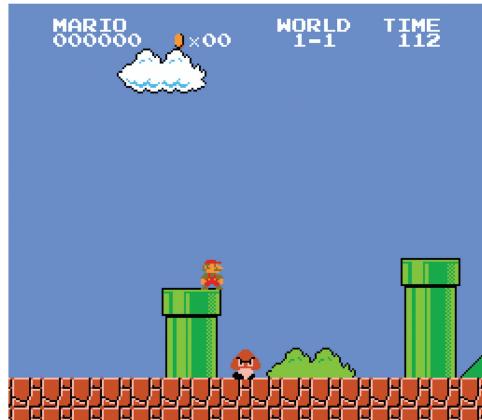


Fig. 6. Super Mario Bros., a very popular platform game, was the second video game involved in our study. Players can move the main character to the left and the right and make him jump over gaps and on platforms to reach the end of a level.

variance with SPSS to analyze main and interaction effects, as well as to derive pairwise differences (based on Bonferroni-adjusted p-values). In case of a rejected sphericity assumption, the degrees of freedom were corrected by means of a Greenhouse & Geisser estimate. Since our Likert scales were based on an established inventory [Douglas et al. 1999] assuming continuous concepts, we treated them as interval scales. Note that the actually analyzed participant sample size was 28, as we had to exclude the data of two subjects, due to their insufficient compliance with the test tasks and understanding of the questionnaire scales. Error bars in the figures indicate 95% confidence intervals.

4.1. Formal Control Test

4.1.1. Completion Time. We found a significant main effect of the gamepad on completion time, $F(2.12, 55.19) = 8.17$, $p = 0.001$. Figure 7(a) indicates that d-pad had the shortest mean completion time ($M = 3.38$ s, $SD = 1.96$). Completion time with d-pad

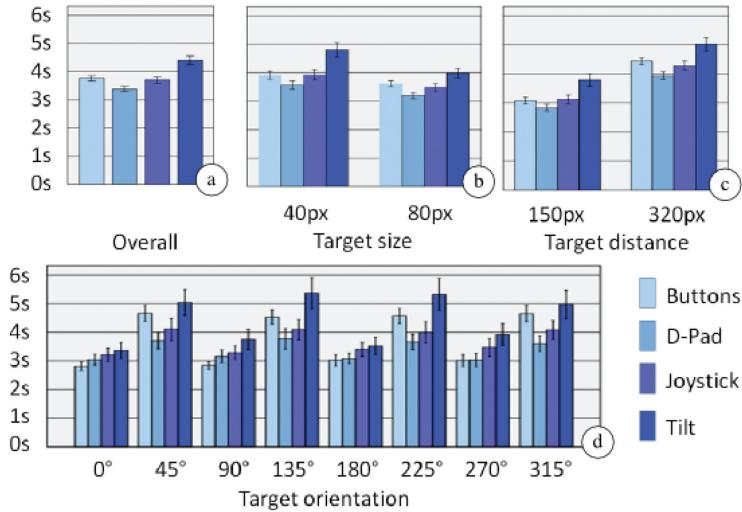


Fig. 7. Mean task completion times for the four gamepad techniques (Directional Buttons, D-Pad, Joystick, and Tilt: (a) overall, (b) separated by target size (c) separated by target distance, (d) separated by target orientation.

was significantly shorter than with buttons ($M = 3.76$, $SD = 1.93$) and Tilt ($M = 4.41$, $SD = 3.38$), $SE = 0.117$, $p = 0.016$; $SE = 0.23$, $p = 0.001$. Tilt had the highest completion times, significantly longer than d-pad and joystick ($M = 3.70$, $SD = 2.44$), $SE = 0.23$, $p = 0.001$ $SE = 0.21$, $p = 0.011$. We did not find any more pairwise differences that were significant when Bonferroni corrections were applied.

As expected, we found highly significant main effects of the other independent factors on task completion time. Distant targets were selected after a longer duration than close targets, selecting small targets took longer than large targets, and selecting targets in nonorthogonal directions took longer than selecting targets in orthogonal directions, $F(1,26) = 384.33$, $p < 0.001$; $F(1,26) = 17.44$, $p < 0.001$; $F(2,16,56.06) = 160.94$, $p < 0.001$. Figure 7(b) illustrates an interaction effect of the factors gamepad and target size: with smaller target sizes, the completion time of tilt increases disproportionately, $F(1,80,47.04) = 6.78$, $p = 0.003$. From Figure 7(d), it is also apparent that gamepad and target orientation were cross-influencing each other: buttons had comparatively higher selection times with targets in nonorthogonal directions than with targets in orthogonal directions, $F(7.84, 203-86) = 5.18$, $p < 0.001$). With regard to an interrelation of gamepad and target distance (see Figure 7(c)), we did not find a significant interaction.

4.1.2. Offset. With regard to offset, we identified significant main effects of all four independent variables gamepad, size, distance, and orientation, $F(2.16,56.16) = 19.25$, $p < 0.001$; $F(1,26) = 8.84$, $p = 0.06$, $F(1,26) = 7.36$, $p = 0.12$; $F(4.39, 114.15) = 5.90$, $p < 0.001$. As can be seen from Figure 8(a), tilt had a significantly higher cursor offset than button, d-pad and joystick, $SE = 0.83$, $p < 0.001$; $SE = 1.17$, $p = 0.004$; $SE = 0.86$, $p < 0.001$. The other pairwise comparisons with Bonferroni corrections did not result in significant differences. We did not identify any significant interaction of gamepad with the other independent variables, that is, the relative profile of selection offset between the gamepad techniques did not vary depending on differences in target size, distance or orientation.

4.1.3. Success. The overall success ratio of selections was very high ($M = 0.98$, $SD = 0.13$). Nevertheless, we found main effects of gamepad and size, $F(2.16,55.78) = 4.68$,

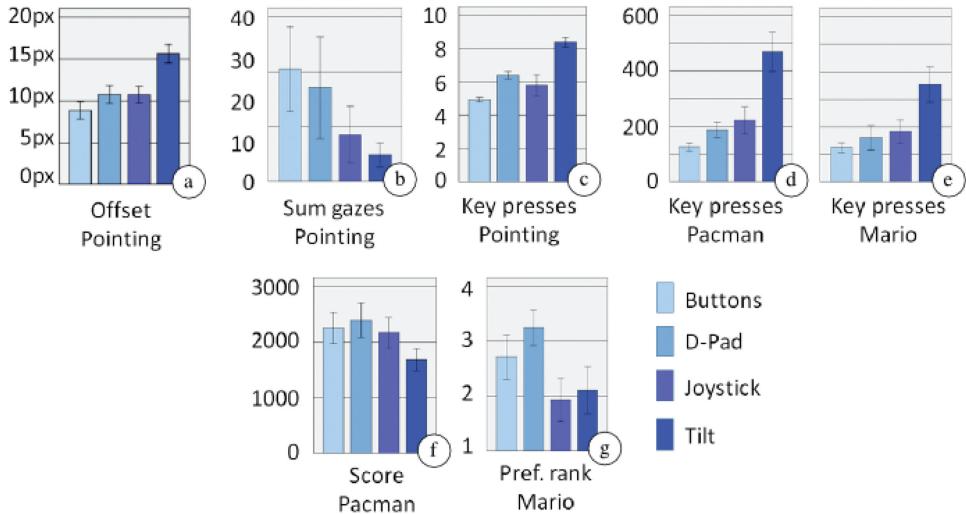


Fig. 8. Comparison of the gamepad techniques Buttons, D-Pad, Joystick, and Tilt with regard to (a) mean offset in the formal control task in pixels, (b) mean sum of gazes per control task, (c) mean sum of key presses per control task, (d) mean sum of key presses per Pac-Man session, (e) mean sum of key presses per Super Mario Bros. session, (f) mean score per Pac-Man session, and (g) mean preference rank with regard to playing Super Mario Bros. (4 = always most preferred, 1 = always least preferred).

$p = 0.012$; $F(1,26) = 15.03$, $p = 0.001$. The only pairwise comparison turning out with a significant difference, after applying Bonferroni corrections, was between buttons and tilt, $SE = 0.004$, $p = 0.017$. We did not identify a significant interaction between gamepad and the other investigated factors.

4.1.4. Key presses. We found main effects of gamepad, size, distance and orientation on simulated key presses, that is, key operations triggered through the gamepad, per task, $F(2.27,56.71) = 13.14$, $p < 0.001$; $F(1,25) = 26.16$, $p < 0.001$; $F(1,25)$, $p = 0.24$; $F(3.26,80.62) = 36.30$, $p < 0.001$. Figure 8(c) indicates that buttons had the lowest number of key presses per task, significantly lower than d-pad and tilt. Tilt had the highest number, significantly higher than joystick and button. No interaction effects between the independent variables were found.

4.1.5. Gazes. When analyzing the number of gazes, we found significant main effects for our two investigated independent variables gamepad and block, $F(1.99,53.96) = 6.77$, $p = 0.002$; $F(1,27) = 20.49$; $P < 0.001$, however there was no significant interaction between them. As demonstrated in Figure 8(b), buttons required significantly more gazes than joystick and tilt, $SE = 3.88$, $p = 0.28$; $SE = 3.61$, $p = 0.001$. The other pairwise differences were not significant.

4.1.6. Subjective Responses. With regard to the questionnaire that subjects responded to after experiencing each control task, we found that the gamepad had a significant main effect on subjects' subjective evaluations of their "performance," "mental effort," "physical effort," "usage difficulty," and "learning effort," $F(3,51) = 3.42$, $p = 0.33$, $F(3,51) = 4.86$, $P = 0.005$, $F(1.93,32.86) = 5.22$, $p = 0.011$, $F(3,51) = 4.049$, $p = 0.12$, $F(3,51)$, $p = 0.021$. Consistently to the above performance-related measures, tilt received lower scores than the other three techniques with regard to these scales, but p-values of the pairwise differences between tilt and the other techniques were mostly above the Bonferroni-corrected confidence level.

The self-reported “ease of usage without looking at the gamepad” also revealed a significant main effect, $F(3,51) = 5.45$, $p = 0.003$. Here, buttons and d-pad received significantly lower (worse) scores than joystick and tilt, respectively (other pairwise differences not significant). Main effects for perceived “accuracy,” “speed,” “comfort,” and “fun” were not significant.

4.2. Pac-Man Game

On average, participants issued 205 navigation commands (see Figure 8(d) for an overview). There was a significant main effect of Gamepad on the number of key-presses, $F(1.93,50.14) = 52.10$, $p < 0.001$. All pairwise differences between the gamepad techniques were significant, except between d-pad and joystick. As can be seen in Figure 8(f), the Pac-Man score was lowest for tilt. Accordingly, we found a main effect, $F(3,51) = 6.76$, $p = 0.001$, and significant pairwise differences between tilt and the other techniques (no other significant differences). The preference rankings did not result in a significant main effect of Gamepad, $F(3,51) = 2.31$, $p = 0.087$.

4.3. Super Mario Bros. Game

The mean number of navigation and action commands commands per game session was 250, see Figure 8(e) for a comparison of the gamepad techniques. Similarly to the previous results, we found a main effect of Gamepad on the number of key presses per session, $F(3,81) = 52.26$, $p < 0.001$, and significant pairwise differences between tilt and the other three techniques (no other significances). The gamepad technique had a significant main effect on the preference ranking related to the Super Mario game, $F(3,51) = 4.09$, $p = 0.011$. As Figure 8(g) indicates, the highest (i.e., best) mean ranking value was obtained for d-pad ($M = 3.25$; $SD = 0.84$) and the lowest for joystick ($M = 1.93$, $SD = 1.02$). Bonferroni-corrected pairwise comparisons resulted in a significant difference between these two, $SE = 0.40$, $p = 0.29$ (no other significant differences).

4.4. Comments and Observations

In the following, we summarize participants’ verbal comments and observations by the test manager during the tests per gamepad.

4.4.1. Directional Buttons. Several participants related the gamepad to respective physical controllers and mentioned the negative lack of tactile feedback. Comments after the formal control test included that the buttons were hard to hit precisely, that especially opposite directions were difficult to press (e.g., switching directly from the left to the right button), and thus control gazes onto the gamepad were needed. Overall, 12 participants explicitly reported that the directional buttons should be larger. This concurs with several mentions of worry raising the finger from the touchscreen during the games and being not able to (re-)hit a button without looking at the controller.

Ten participants had positive remarks for the directional buttons including “*It worked like expected*,” “*It’s self-explaining and easy to learn*,” and “*You can’t go wrong with this control*.” One test person suggested to use the phone’s vibration to indicate when a button has been hit correctly.

4.4.2. Directional Pad. For the formal control test, many participants appreciated the possibility to move diagonal in comparison to the directional buttons. Yet, four participants found the areas for diagonal movements difficult to hit. The opportunity to drag the finger on the d-pad led to several side effects: four participants mentioned that they controlled the element in the first study phase in a wavy line, four others reported that they slowly drifted beyond the sensitive area of the d-pad while keeping their gaze on the remote screen during both control test and the games.

Six participants found the directional pad “easy to learn,” “comfortable,” or “responsive”. One test person would have preferred a mirrored version, that is, the d-pad on the right side. Another one suggested to omit the limitation of the d-pad area or to add a vibrational signal when leaving the touch-sensitive area.

4.4.3. Joystick. Having completed the formal control test, 16 participants had very positive comments for the joystick such as “intuitive” and “very comfortable.” One participant described it as “sluggish,” another one as “too sensitive.” The floating design was criticized only by one test person who found it “irritating that the joystick appears anywhere.” Three participants reported that they would have favored the joystick on the right side. Comments for *Pac-Man* were mostly negative: 15 participants admitted to have had major problems with controlling the character. Remarks with regard to *Super Mario Bros.* were more positive, some participants found the combination of pressing the action button on the right and dragging the joystick knob on the left for jumping sideways unusual or wished for a better sensitivity of the joystick for more precise movements.

One striking observation confirmed by verbal remarks was that several participants tended to slide their fingers beyond the touchscreen: while staying focused on the remote screen and dragging the joystick knob they sometimes slid to the edge of the display and thus unintentionally interrupted the current action.

4.4.4. Tilt. After the control test, 11 participants had negative remarks concerning the accuracy of the technique such as “the neutral position is hard to find” or “it was difficult to stop the character.” Two persons called it “easy to use” and “responsive”, one test person experienced with the gesture-based game console *Wii* found it even “*very easy and accurate*.” Two participants would have preferred an inverted vertical control (i.e., tilting the device towards the body for moving the character downwards), one (right-handed) player favored the button on the left side.

Comments regarding the *Pac-Man* game were thoroughly negative and players obviously had problems to issue direction commands timely. They often missed junctions and could only navigate the game character at corners where it stopped moving. The formal control test and *Super Mario Bros.* revealed the awkward combination of traditional action buttons with a tilt control: users tended to unintentionally move their finger above the action button when tilting the device and eventually missed the action button. As a consequence, several participants found the action button on the tilt controller too small. Yet, the overall verbal comments for the platform game were much more positive than for *Pac-Man* (“good,” “easier than expected,” “very responsive.”) Four participants mentioned a flight simulator as a potentially more suitable game for this type of control.

5. DISCUSSION

In this section, we refer back to our original research hypotheses and discuss the results with regard to our former expectations.

5.1. Directional Buttons

We hypothesized in *H1a* that the usage of directional buttons would require the most attention on the gamepad. This could be partly confirmed, as the average number of gazes per task was significantly higher than for two other techniques (tilt and joystick), but similar to the d-pad. We found the same grouping of directional buttons and d-pad vs. tilt and joystick in the subjective rating scores. As could be expected, performance with directional buttons was found to be highly sensitive to target orientation. However, this restriction did not hinder participants to use directional buttons efficiently. As

expected, the number of key presses was low in comparison to the other techniques (but not significantly lower than for the joystick technique).

H1b is partly confirmed: the directional buttons do not perform best, yet belong to the group of controllers which enabled highest scores for the Pac-Man game (only tilt performed significantly worse than the others). Whereas this control with its four buttons (corresponding to the four possible directions in the Pac-Man game) was described as intuitive, most striking negative issues were sporadic misses of the buttons and subsequent corrections while the participants gazed at the large screen. As mentioned above, 12 out of our 30 participants explicitly stated that they consider the size of the directional buttons too small. However, any redesign with larger buttons must take into account the less compact button arrangement – greater distances between the buttons might be another potential source of mistakes.

5.2. Directional Pad

Hypothesis *H2a*. is confirmed: in the formal control test, the d-pad outperformed the alternatives in terms of completion time. The 8-way controller is a well-known input technique and well-suited for such generic 2d control tasks. The problem of leaving the sensitive area of the d-pad and thus stopping the current movement (which was mentioned by four participants) led to irritation, yet did not have any impact on the technique's superiority in speed. In addition, the participants triggered significantly more movement commands with the d-pad than with the related directional buttons. We ascribe this attribute to the swiping feature which enables and obviously encourages quick corrections without looking at the gamepad (e.g., by directly dragging the finger from the left to the right side of the d-pad).

In *H2b*. we expected the participants' subjective preference of the d-pad for a platform game like Super Mario Bros. Indeed, we found that participants rank the d-pad significantly better than the joystick and the tilt control (however, not significantly better than the directional buttons). This confirms our expectation in major parts. Surprisingly, this advantage is really a subjective one: both spent lives and level completions were similar for all gamepads, none of them provided any significant gameplay benefits. The choice of the gamepad for this type of game, with less critical reaction times and only left/right movements in comparison to Pac-Man, seems to be of less relevance for the objective player performance.

5.3. Joystick

H3a. We expected the joystick technique to be more accurate than alternatives due to its touch-based sensitive approach. This hypothesis is rejected by our results. The joystick is only significantly better in terms of accuracy than tilt, even (nonsignificantly) worse than the buttons. While in general the joystick was taken up positively by participants, it obviously was difficult for them to exploit the short dragging gestures, quickly hitting a button seems as suitable. In the presented study, we applied one configuration of the sensitivity levels for the joystick – exploring this topic in more detail and investigating a potentially better configuration could be subject of a follow-up study.

H3b. assumed that the joystick would be the best-rated gamepad for Super Mario Bros. This hypothesis is rejected: in the subjective assessment, the participants ranked the technique worst. While its suitability for controlling the game without looking down is appreciated, the two-step touch approach (first pressing and then dragging) of the joystick turned out to be odd for a platform game where the players expect immediate movement of the game character when touching the screen. Further, the combination of pressing the action button on the right and dragging the joystick knob on the left for jumping sideways was difficult for many participants.

5.4. Tilt Control

As expected in *H4a.*, the tilt control turned out to have the lowest accuracy of all the evaluated gamepads. It also performed worst in terms of completion times, especially for small targets. These results are in line with related prior studies on tilt-based remote controls [Baldauf et al. 2013; Boring et al. 2009].

H4b. is confirmed: using the tilt control, participants scored significantly fewer points in Pac-Man than with the alternatives. Such smartphone gestures proved to be not suitable for quick discrete direction changes as required in the Pac-Man game. One striking problem in the platform game Super Mario Bros. was the bad combination of tilt gestures and a traditional soft action button, which was easily missed when the device was tilted. From the more positive feedback on tilt-based game controls in previous work [Chehimi and Coulton 2008; Gilbertson et al. 2008; Medryk and MacKenzie 2013], we conclude that such controls are better suited for custom-designed games than for the two investigated traditional game genres.

6. LIMITATIONS

Creating and implementing game controls for touchscreen smartphones include a lot of design decisions. To setup a sound study with comparable conditions, we deliberately focused this experiment on directional controls to navigate a game character. We kept the action button unmodified, even simplified. Further, we deliberately ignored haptic feedback through the vibration module to keep the number of study conditions reasonable and explore the potential of plain touchscreen gamepads. We outline promising ways to include vibration and respective future work in the final conclusion section.

7. CONCLUSION AND OUTLOOK

We presented the first comprehensive study on soft gamepads for controlling remote video games through a smartphone. While it can be expected that smartphones will not replace hardware game controllers, they can provide a promising alternative in settings, where no dedicated input hardware is available, such as for casual games at home or spontaneous gaming on interactive public displays. An increasing amount of respective applications in mobile app stores and high download numbers show this trend.

In our study, the directional buttons proved their strengths in simple navigational tasks restricted to the four main directions. However, this gamepad is impacted most from the lack of tactile feedback and requires the most attention of its users, especially when they need to correct the course or quickly switch between the buttons. Concrete recommendations for applying this technique include the use of a high-contrast color scheme to keep gaze durations to a minimum and allow glances from the corner of the eye as well as appropriate customization techniques. While *Gestureworks*¹³, for example, provides a toolkit for freely assembling touch controls, a soft gamepad for casual games and interactive public displays should not provide an extensive feature-rich editor but offer support for quick minor adaptations such as customizing the size and location of buttons, changing the sensitivity of a joystick, or mirroring the entire gamepad.

While a directional pad is familiar to many users, we showed that the soft d-pad encourages drifting beyond the actual control, when the gamer is focused on the remote screen. The same is true for the joystick where we did not limit the dragging area but users sometimes hit the edge of the display. Both remote control techniques could benefit from vibrational signals when the user approaches the border of the d-pad

¹³<http://gestureworks.com/>.

or the joystick field, respectively. Performance-wise, the floating joystick turned out to be very promising technique for soft gamepads reducing required glances at the mobile device. However, it is currently unfamiliar to many users and partly tricky to handle, especially when a game action requires dragging by one finger and tapping by another simultaneously, for instance, when making a game character jump to the right. Tilt turned out to be either not well-suited or rejected by users for any of the investigated tasks. A smartphone tilt control may only in rare cases be a suitable controller replacement for a video game (e.g., for continuous movements like in the proposed flight simulator) but rather require custom-made games, as indicated by related research on mobile games.

The investigation of additional game genres (such as first person games) is one topic for future work. Further, we are interested in the sound integration of vibrational signals and respective vibration patterns. Since the present study deliberately focused on directional commands, advanced on-screen controls for triggering further game actions should be investigated. Examples include suitable soft-button arrangements and novel smartphone techniques for efficiently triggering so-called combos, sets of actions quickly performed in sequence.

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