Entertainment Computing 5 (2014) 205–209

Contents lists available at ScienceDirect

Entertainment Computing

journal homepage: ees.elsevier.com/entcom

Navigating in 3D space with a handheld flexible device ☆

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ARTICLE INFO

Article history:
Received 29 January 2014
Revised 14 May 2014
Accepted 12 July 2014
Available online 19 July 2014

Keywords:
Games
Spatial navigation
Flexible device
Deformable input

ABSTRACT

Prototypes for handheld, flexible devices are becoming popular in the research community. We explore opportunities in the domain of mobile gaming with flexible devices, by focusing on deformable inputs to control navigation in 3D virtual environments. We compare two sets of bend gestures to control a first person camera in a 3D maze, one inspired by console game controllers, and the other inspired by PC game controls (i.e. mouse and keyboard). Our results shows that users prefer the set inspired by the console controller: moving forward and backwards mapped to the top left corner, turning to the top right corner, and strafing to the bottom right corner. This results in lower wall collisions and an overall better user experience. We propose design recommendations to create deformable game controls in 3D spaces.

1. Introduction

Deformable user interfaces (DUI) propose the physical deformation of an object as an input technique, such as bending, twisting, folding, and stretching [1]. The thin, lightweight, and flexible nature of these devices support such novel interaction techniques. When using bend gestures on flexible devices, users leverage the tangible, kinesthetic feedback of manipulating paper documents (e.g. turning a page on a book), providing an improved experience [2,3].

To explore the potential of bend input, researchers have proposed various applications, most of them focusing on creating mobile apps: icon navigation, maps, e-book readers, contacts, and photo browsing [1,2,4]. As the next generation of smartphones emerges [1,5,6], flexible displays offer an unprecedented opportunity to expand the field of mobile entertainment, as games are the most popular and used mobile applications [7]. Deemed physically engaging [8], bend gestures offer a unique opportunity to explore new interactions and input technologies for mobile games: moving characters on a 2D plane can easily be mapped to bend gestures [9].

However, many games involve more complex actions than navigating a 2D plane: for instance, players often need to move their character in 3D space. In first person video games, this translates to commands to navigate and orient the player, or to select the viewport. Beyond using a flexible device as a smartphone, we see an opportunity to use them as a next-generation video game controller to accomplish such actions.

In this paper, we explore different input sets for bending a flexible handheld device to move a character in 3D space, from a first person perspective. We base our inputs on game console controllers, and personal computing (PC) game controls (mouse and keyboard). In our study, participants navigated a 3D maze with each input set (Fig. 1). We discuss the intuitiveness of the methods and propose design recommendations on using flexible devices as game controllers.

2. Related work

To develop a system which would enable users to navigate intuitively in 3D space with a flexible device, we considered two areas of research: how individuals use flexible devices, and how people navigate in 3D space. We present key prior works that form the basis for our current study.

2.1. Flexible displays

Schwesig et al. [10] envisioned the purpose of flexible displays in future products: the authors imagined a flexible handheld device, slightly larger than a credit card, where the entire body of the device would be used for interactions. They used bending to control zooming and transparency in the interface. With their prototype Gummi, they found that bend input was helpful for simple tasks that can be conceptually mapped to physical gestures, yet it was not useful for complex tasks such as text input. Additionally,

☆ This paper has been recommended for acceptance by Steffen P. Walz.
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http://dx.doi.org/10.1016/j.entcom.2014.07.002
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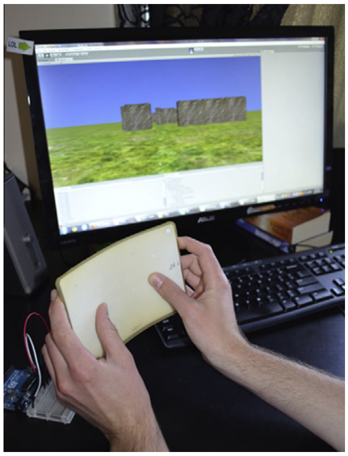

Fig. 1. Users can manipulate a flexible device to navigate a 3D maze.

they observed that people responded well to semantically opposed operations for bending.

While the Gummi prototype used a rigid display with flexible handles, other researchers decided on using projection to better evaluate the possible flexible interactions while commercial flexible displays are still unavailable. Konieczny et al. [11] projected an image on a bendable device using a fisheye camera, allowing the user to simulate the interaction with a flexible display. The device was piece of laminated paper with solid edges on each side. Two corner markers tracked the deformations of the device. The authors explored medical 3D volume visualization, a magic window (where you see the volume before you slice into it), and a shader lamp.

Recently, Steimle et al. [12] presented Flexpad, a real-time tracking system for flexible materials that does not use markers. This system used a Kinect sensor, a projector, and sheets of flexible materials. Flexpad enabled bending the device for a variety of tasks, including manipulating character animations. Overall, Flexpad can detect detailed deformation and offer a complex and board interaction language.

PaperPhone [2] used a functional flexible display to create the first flexible smartphone. With PaperPhone, Lahey et al. studied what bend gestures users were comfortable producing, and how they preferred the bend gestures to match software actions. They found a link between the polarity of the action and the direction of the movement: users selected to bend up to go left, and down to go right in their prototype, which contained a rigid bezel on the left.

With the Kinetic Device [1], Kildal et al.'s primary goal was to develop design guidelines for mobile flexible devices. The prototype, which uses the smartphone form-factor, featured an image browser and a music player. The Kinetic was designed to be used with two hands and to provide "good use of spatial mapping of actions" [1]. They observed that individuals preferred lower-resistance flexible devices to higher resistance flexible devices due to fatigue [13]. The Nokia researchers expressed the importance of identifying interactions that would benefit intrinsically from a deformable device.

Only one set of researchers have approached the problem of games on a flexible device. Ye and Khalid developed Cobra, a flexible device for mobile gaming [8]. Cobra used a projector and a flexible mobile device, like Konieczky's system, though in this case, the whole system was portable as the projector was shoulder-mounted. They developed a few small 3D demos, though the nature and breadth of their demos were not described in their short paper. The Cobra system took advantage of the analog nature of flexible device input to create physical metaphors, such as deforming the device to control a digital car's speed. Ye and Khalid argued that these hands-on metaphors, combined with the passive haptic feedback of the flexible device, could be used to make physically engaging games.

2.2. 3D games

Navigation in 3D games can be presented in either the first or third person perspective. In the former, the player moves around the environment similarly to a tourist that explores a new city: by walking around. In the latter, the player has a bird-eye-view, or a map view of the scene. Each perspective offers different types of information and levels of immersion [14], and an impact the player's navigational abilities [15].

For 3D navigation, the two most common inputs use either the two joysticks located on a gamepad, for console games, or a combination of mouse and keyboard, for PC games [16]. In comparing the use of the mouse, the keyboard, a joystick and a gamepad, Lapointe et al. [16] found the mouse to outperform the other three inputs, although it only offers two degrees of freedom (one translation and one rotation). They also note that the main advantage of the gamepad is its portability, as it does not require a desktop surface to be operated.

El-Nasr et al. [17] explored which areas of the screen users look at the most when playing different genres of 3D video games. The considered both first-person shooters (FPS) and third person action-adventure games, as well as three levels of expertises. In the FPS scenario, users focused solely on the center of the screen. In the third person action-adventure game, users still focused predominantly on the center of the screen but their eyes wandered to different areas of the screen. When using handheld flexible displays, parts of the screen are sometimes obstructed from view by the deformation of the device or occluded by the hold. This research suggest that first person game formats may be more suitable for flexible displays, because the center of the device is seldom obscured during input deformations.

3. Navigating 3D space with bend gestures

In a first person perspective video game, users can typically perform the 3D navigation movements of moving forward, back, left, right, as well as turn left, turn right. "Moving" refers to the character movement translating to the left or right (often called "strafing", or "side-stepping"), while "turning" rotates the body on itself in relation to the camera movement [16].

We are interested in investigating how to implement bend gestures to navigate in 3D space on a mobile flexible device. We propose two different sets of input deformations based on the two primary traditional input methods for video games: console controllers, and mice and keyboards. In a traditional PC game, the camera movements are typically controlled by the mouse, while moving movements are controlled with the keyboard. The movements are discrete, controlled by buttons. Console controllers use two analog joysticks - one to control the character's movement, and the other to control the camera's orientation.

The first set of inputs, set A (Fig. 2), is inspired by the console approach to movement. The left joystick on a console controller normally controls character movement and the right joystick controls camera movement (turning). We designated the top left location (using both directions) to control movements forward and backwards in 3D space, respectively. The player can turn the camera left and right by bending the top right corner backwards and forward, respectively. The strafing movements are located on the bottom right corner of the flexible device. As this movement is deemed less important for gameplay in console controllers, we

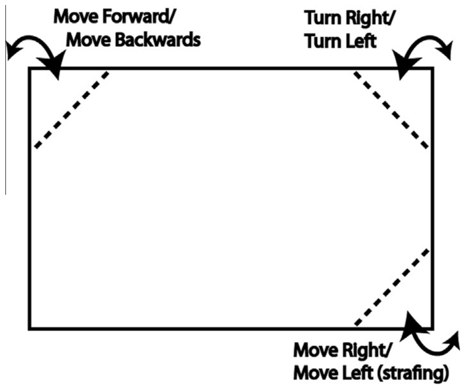

Fig. 2. Bend gestures of set A mapped to navigational actions. Dotted lines indicate where the device is bent.

placed it in a less preferred location [2,18]. We selected pairs of opposing movements to be placed in the same location [10]. In this case, the directionality mapping corresponds exactly to that of PaperPhone [2].

The second set of inputs, set B (Fig. 3), is inspired by PC input controllers. In this set, the user bends the top of the flexible device up and down to go forward and back. To move left, the player bends the left top corner of the device towards him/her. In PC games, players perform strafing often, hence we placed strafing on the top corners since this is a preferred location [2,18]. This action is mirrored on the right. The right and left sides of the device are bent down to turn the camera right and left respectively. We separated the two turning actions to reproduce the discrete aspects of turning left and right on the keyboard, done using two arrow keys. We improved the mapping between the direction and the action from that of PaperPhone [2], by making use of the full device: a left action is mapped to a gesture on the left of the device, and a right action is mapped to a gesture on the right of the device.

4. Study

We designed a study to evaluate the effectiveness and preference of the bend gesture mapping set. Participants manipulated our flexible display prototype to navigate a 3D maze, and were asked to identify their preferred set of inputs. 12 individuals tested our prototype (6 male, median age of 24). Their gaming experience varied from novice to experienced (average 3.3 on a scale from 1, novice, to 7, expert), and there were as many console gamers as PC gamers. All were novices with deformable controls and flexible displays.

4.1. Prototype

The prototype developed was a thin flexible device made out of silicone, measuring 120 mm $\times$ 165 mm $\times$ 4 mm. Fig. 4 illustrates the different components of our prototype. We detected bend gestures using four bi-directional FlexPoint bend sensors, each angling from the center to a corner. We recorded the data from the bend sensors through an Arduino Uno device. The virtual environment and maze were developed using Unity 3D, which also processed the bend sensor data.

We created a simple maze with one decision point, three hallways, and nine angles. Fig. 5 displays the maze created for the experiment. The maze was presented on a computer monitor located in front of the device, a similar methodology found in Kildal et al. study [19].

4.2. Experimental methodology

Participants sat down in a quiet room in front of a desktop computer with the prototype. The experimenter explained to the participant that they would be using the flexible device to navigate a maze, and that they should try their best not to run into the walls of the maze.

Participants tested each set of gestures once. The order of sets tested was counterbalanced between participants. They trained on each set before the task, and had permission to refer to a sheet illustrating that particular set of inputs during gameplay (similar to Fig. 2 and Fig. 3). We recorded the time to completion and the number of wall collisions.

Upon completing the maze with each set of inputs, the participant evaluated the intuitiveness and difficulty of each aspect of that input set (forward, backwards, left, right, and turning). Finally, users were asked to select their preferred set, and explain their preference.

5. Results

5.1. Time to Completion and Wall Collisions

We recorded the time participants took to complete the maze for each set of gesture. A pairwise t-test revealed that users did not navigate the maze noticeably faster with set A (M = 117s, SD = 69.0) than B (M = 121s, SD = 72.5) ($p > 0.05$).

On average, users hit walls 10 times in set A (SD = 7.1) and 27.3 times in set B (SD = 13.4). A pairwise t-test showed that these values are significantly different ($t(17) = -3.95$, $p = 0.002$).

5.2. Intuitiveness and Difficulty

After exploring the maze, users were invited to evaluate the intuitiveness and difficulty of each command on a 7 point likert scale (1 is difficult, 7 being easy). A pairwise t-test found that set A was easier to manipulate than set B ($t(8) = 3.09$, $p = 0.018$), with set A averaging 4.6 on the difficulty scale (SD = 1.4), while set B

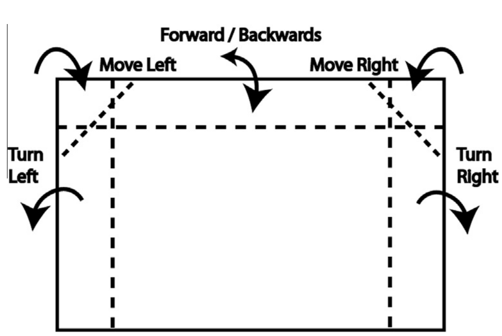

Fig. 3. Bend gestures of set B mapped to navigational actions. Dotted lines indicate where the device is bent.

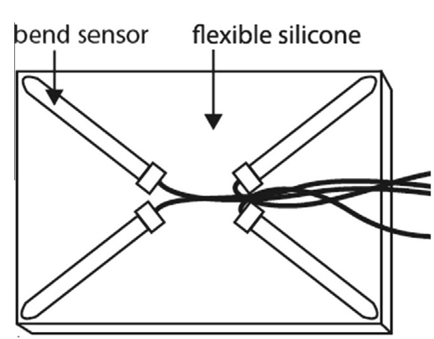

Fig. 4. Diagram of flexible device prototype. Four bend sensors were affixed to a silicone surface.

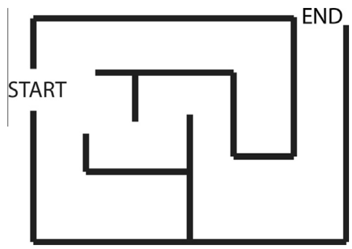

Fig. 5. Top view diagram of the maze.

averaged 3.8 (SD = 1.6). A pairwise t-test did not reveal any statistical difference between the two intuitiveness scales ($p > 0.05$).

5.3. Preference and qualitative data

In the post-test questionnaire, participants were asked which set they preferred using and why. 83% of participants preferred set A over set B.

Set A: Many users found set A to be "easier" or "more intuitive". Users claimed that it was easier to control movement with set A, and appreciated that it required less exertion on their part to manipulate.

In set A, participants were most comfortable with moving forward and backwards, and followed by with turning left and right. However, some participants experienced difficulty with the mapping of left and right for both moving and turning to bending the corner of the device backwards and forward: they found it either confusing, hard to keep track of, or suggested that it should be reversed. Participants did not enjoy strafing (moving left and right), and we did notice that it was rarely used at all with this set of controls.

Set B: Most users found set B frustrating to use. They often were confused as the gesture to use, misremembering the mapping. For instance, a few participants tried to pull the sides up instead of pushing them down to turn left. Additionally, users found that they could not overlap commands the same way they could with set A, which decreased their efficiency. For example, they could not turn and move forward at once.

Unlike in set A, where users hardly used the strafing commands, participants moved left and right more than they turned left and right.

This interaction set took a higher physical toll on the device, more than set A. The prototype curved, and the adhesive holding the sensors in place weaken, as set B involved larger bends located in more locations on the device.

6. Discussion

Overall, the study participants preferred the console-inspired control set (set A) to the PC-inspired control set (set B). Set A was more intuitive to most users, and they found it gave them greater control, illustrated by a lower amount of wall collisions in set A. We observed that most individuals learned set A faster.

Participants found turning left and right in the console-inspired control set (set A) confusing because it involved bending the controller forward and back. In PaperPhone, participants preferred this exact gesture to action mapping [2]. However, Paperphone only offered bend gestures on the right half of the device, and there were no forward and backwards actions proposed in their application. While this result confirms that directional data has to be mapped directly to the direction of bending in a flexible device, it might be worth it to investigate this issue further, as the two studies present partially conflicting results.

Participants seemed to favor using the top right and left corners of the device in both sets, which corresponds to the results of Lahey et al. [2] and Warren et al. [18].

In set A turning right and left were controlled by bending the top right corner of the device. In set B, the control set inspired by classic PC gaming controls, turning right and left were controlled by bending the entire right or left side of the device respectively. With a device of these dimensions and malleability, participants had greater control using the corners of the device than using the sides to maneuver through the maze. They also felt little discomfort or fatigue when using top corners. With this in mind, set B could be improved by swapping the turning and strafing gestures (i.e. turning functions would be mapped to the top corners of the device, and the edges would be used for strafing), to be more consistent with the results in set A.

We found that participants did not generally bother bending the bottom corners of the device, perhaps due to the way they were holding the device. Many players left the bottom edge of the device propped on the table. Users found this position to be more comfortable and requiring less effort for gaming. If, upon further evaluation, this appears to be a general trend, controls manipulating the bottom edges of this size of mobile device would be seldom used.

The goal of the study was to explore a flexible device as a game controller by focusing solely on 3D navigation tasks. In a real game setting, the controller is also used for interacting with other elements of the game and the virtual environment (selecting a target, jumping, etc.). Given those additional controls, we believe that set A would be better suited to allow players to handle them. The symmetrical configuration of this set would make it easy to add more controls in unused locations, along the sides for instance, and we believe it would minimize user confusion. On the contrary, set B would need to map controls to additional directions, instead of additional locations, which would increase the cognitive load of the user.

It is important to note that while our current prototype may look like an external controller without a display, we created this prototype with the goal of integrate a functional flexible display to the sensing technology. This would be closer to the Nintendo DS game controller, that integrates both two joysticks and a display on a portable device.

Finally, the material with which the flexible device is made out of is very important to the user experience. Previously, researchers have observed that users prefer more malleable materials to minimize fatigue [1]. They have also observed that flexible materials that keep their shape can be better for more complex, detail-oriented interactions [12]. However, for gaming interactions, we recommend that the flexible device to snap back to a flat position when not receiving active pressure from the user, similarly to the PaperPhone prototype [2].

6.1. Design recommendations

Overall, set A offers a better configuration as a game controller on a flexible device. We offer a few design recommendations for creating a bending system that involves hand minimal movement, and is easy to control.

1. **Utilize symmetrical actions.** We recommend placing gestures in pairs, either by varying the location only, or the direction only, with a preference varying the direction. This will improve learnability and memorability of the system, and an enable designers to have more actions available to users.
2. **Place high frequency actions on top corners.** As the top corners are a preferred location, we recommend mapping frequent and important actions to them. This results is coherent with prior work [2,18].

3. **Use bottom gestures for unimportant actions.** Bottom corners bend gestures are not performed often, as participants need to reposition their hands to perform them. They are ideal for infrequent actions or actions which should not yield false positives.

6.2. Limitations

While we can generate interesting design recommendations from this study, we must note a number of limitations. The prototype was a preliminary one, and the wires in the back distracted a few users. Some mentioned being "extra-careful" with it. In addition, the prototype material became permanently curved in time, keeping the shape of previous bends. This frustrated and confused a few users towards the end of their session. The prototype also did not have an embedded display, like the intended final product. While this setup has lead to successful studies (e.g. [1,19], it would better reflect the intended final product.

Our experiment only explored and compared two sets of bend gesture mappings. It would be interesting to assess the performance measures proposed by Klochek and MacKenzie to compare our new input set with traditional game controllers [20]. Finally, our user population was small, and the study would have benefited from a more cohesive group of users (two of our users were much older than the rest).

7. Conclusion

In this paper, we explored the use of a bendable device as a controller for 3D navigation in games. Our participants moved through a maze with two different sets of bend gestures, one inspired by console game controllers, and the other inspired by PC game controls (i.e. mouse and keyboard). We found that set A, inspired by the console controller, was preferred by participants and resulted in almost a third of the errors of the other set. Participants found that the top corners were very easy to manipulate effectively as part of a navigational control, however they were unlikely to use the bottom edges of the device. However, we found no set preference in terms of intuitiveness of the gestures to the actions.

We recommend further research to explore the flexible device's tangibility, by exploring materials and sizes to ensure comfort, adequate deformation measurements and long term use. We could investigate adding additional bend sensors and create a more complex sensor configuration to measure more detailed bending information. This might make the edge-bending commands more effective. It would also be interesting to explore additional mapping of directional data with bend gestures, to improve the winning set. A potential approach to understanding how users might prefer to use flexible devices for 3D games might be to create an interface that enables users to map their own commands. This way, researchers could analyze different sets of user input data (based on age, gender, handedness), and determine what users find natural as inputs for 3D gaming applications.

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