Up And Down And Along:
How We Interact With Curvature

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Abstract

Non-flat interactive displays have one very distinct property that differs from the touch displays we use on tablets or smartphones: the spatial structure that defines their non-flatness. In this paper, we investigate one specific class of spatial structure – planes bent in one dimension with both concave and convex curvature. We study horizontal pointing and dragging along those bends to see how it differs from flat displays. Structure can also enable new interactions that have not been possible with flat displays, e.g. perceivable vertical dragging across a horizontal structure. Overall, we found that accuracy of interaction as well as subjective preference can be increased, and that the new interactions can enhance existing direct touch control.

Introduction

Based on an analysis of the design space for non-flat displays (Figure 1), we found that the relation between architectural structure, e.g. *concave* and *convex,* and interaction style, e.g. *touch*, has not been the focus of much research yet. Roudaut et al. [3] looked at targeting accuracy for curved surfaces; we would like to add recommendations on how to use such structures for interaction. Based on recent developments in car infotainment systems, the scenario for our studies is an automotive cockpit. The enormous amount of available

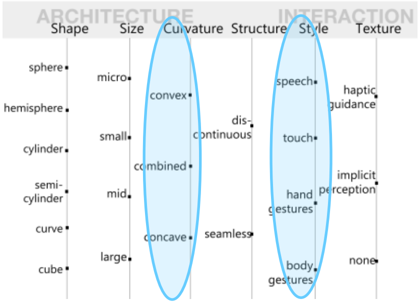

Figure 1. Design space for non-flat displays. [4]

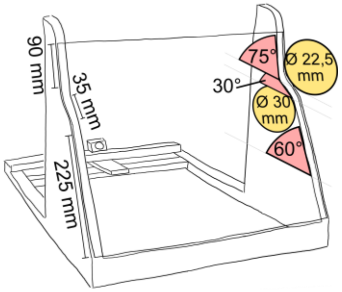

Figure 2. Design of the prototype with a convex and a concave bend. It consists of a bent 4 mm acrylic panel. A Rosco projection foil and a MicroVision laser projector are used to display the rear-projected image. FTIR for touch sensing uses a silicon foil of 1mm thickness, two IR strips on the top and bottom side of the acrylic and a Point Grey Firefly camera equipped with an IR lens.

functionality is often controlled via a central information display (CID) in the top region of the center stack in combination with a central control element, often a knob. A recent trend are touch screens instead of the combination of a display with a remote knob. Touch interaction, however, relies on visual feedback. Thus, it is likely to distract the driver from the street and to concentrate her visual attention too much on the display area. There are approaches to add nonvisual feedback to touch screens, such as remote haptic feedback [2] or electrovibrations [1]. These improve interaction in the lab, but it remains unclear how they perform in the presence of driving vibrations in a car. Non-flat touch displays can provide passive haptic information and thus allow the display to be explored and controlled blindly to a certain degree.

Prototype design

We built a prototype of a center stack with touch functionality on its entire surface. There were some external constraints to its shape: It had to contain a display area located in the place of current CIDs, as glances there are common and do not distract from the view through the windshield too much. It was also designed to provide a larger, comfortably tilted multi-purpose area in a good reaching distance. Transitions between these areas should be smooth and coincide with the smooth distance shifts of the dashboard and cockpit design. The prototype functions like recent interactive tabletops [6] (for details see Figure 2).

Pointing and dragging

In a first step, we investigated basic tasks like pointing and dragging on non-flat and planar surfaces. Our hypothesis was that structured (as opposed to planar) displays improve the speed and accuracy of interaction. The independent variable *structure* contains five levels: convex and concave bend and the three combining flat areas in different heights and with different tilt angles. We set up three different tasks, which are depicted in Figure 3. ***Task 1*** is a pointing task. As the driver's normal starting point for interaction on the center stack is the steering wheel, we decided for directional movements from left to right with different approaching angles (120, 150, 180, 210 and 240 degree on a radian circle). This directional movement also prevents a possible occlusion of the target buttons from the driver's perspective. The order of structures and directions was randomized for the study. Buttons are appearing one after another, and only the duration of movements from left to right is measured. ***Task 2*** was defined after the observation that physical buttons are often aligned in a row. When looking for a specific function, e.g. a certain radio channel, we scan horizontally through these elements. If we feel that the touch of the first button is askew, we can correct the position of the finger to touch the next button more precisely. Again, a directional movement from left to right was tested, and the order of structures was randomized. ***Task 3*** looked at the control of continuous values through sliders. We expected the touch slider to be easier to follow if it follows a display structure. Therefore, participants had to drag a slider to a given value (20, 40, 60, 80 and 100%) and were timed. The order of structures and values was randomized. We used a within-subjects design, so all participants tested all structures. Task 1 and 2 were repeated after task 3, to capture training effects. For all tasks, we measured duration and collected subjective feedback regarding workload and usability. We used questionnaires to collect subjective feedback after each test. During the study, participants were sitting in front of a steering

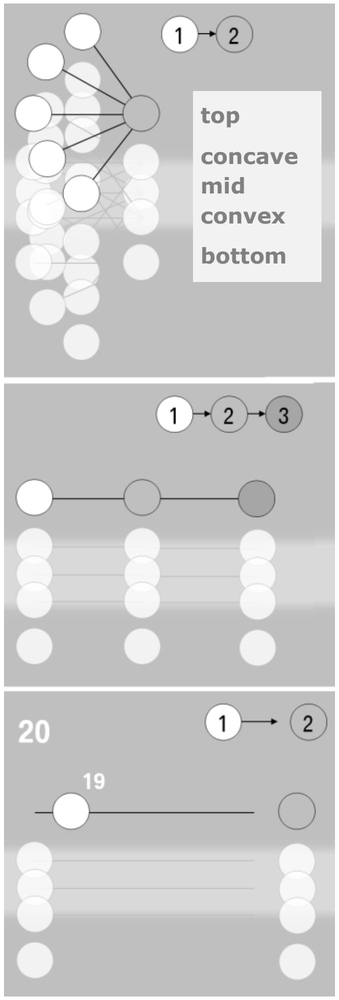

Figure 3. Basic tasks. Top: Task 1 *Tap from left to right*. Middle: *Task 2 Tap orientation*. Bottom: Task 3 *Slide orientation*.

wheel as in a car. The prototype was located to their right as the center stack. Participants were advised to imagine a parking situation where they have their left hand on the steering wheel at a 9 o'clock position to ensure a consistent posture during the study. The right hand and the visual attention were focused on solving the tasks. The 16 participants (4 female) with a mean age of 27 were advised to solve tasks as quickly as possible, but still correctly.

In the first task, there is a significant difference between interaction times to tap a button in the different areas. Post-hoc tests reveal that duration is degraded by the concave bend compared to all other areas. Participants commented that the concave bend was harder to hit because of its narrow width, so that their finger was stopped when the nail hit the surface. On average, taps on the convex bend require the least time (0.609 sec on convex, 0.747 sec on concave bend). The mid area, even though considered as a kind of rail that offers a convenient angle to tap on from above, does not provide a significant time advantage.

The second task was achieved fastest when interacting on the convex bend. *Structure* influenced interaction speed significantly; again, interaction on the concave bend is slower than on all other areas. For the third task, an ANOVA did not show significant differences. However, the best results were achieved on the convex bend (t = 4.33 sec there, t = 4.90 sec for mid area).

Overall, there was no significant difference between results for top and bottom area in all tasks, indicating that height of the areas did not influence the results.

When asked about the potential for bends to improve usability, participants' ratings increased from the first to the second run of tap tasks, indicating that users need to get used to this new kind of interface.

Subjective feedback regarding the slider task showed best results for the convex bend in a combined rating for feeling fast, secure and comfortable. Together with the shortest time in that task, this shows that structure is helpful in linear dragging tasks. The screen with its different structures was irritating for some participants in the beginning. However, when asked in the end if they like the idea to have it in a car, an average rating of 5.6 (1 = *not at all* to 7 = *very much)* was achieved.

To sum up, we found that structures provided guidance for interaction, where the interface concept supported this (e.g., dragging along a ridge). However, as the results of the concave bend show, surfaces need to be designed carefully to not *degrade* performance.

Dragging up and down different curvatures

In contrast to flat surfaces, curvatures can be perceived haptically. Bends as in our prototype have different sections that can be felt. For an eyes-free interaction, the end of a bend can for example be used as a trigger point in a dragging interaction.

We now wanted to examine how accurately and how reliably those positions can be recognized across users. To investigate different variants of dragging, we set up a study with three independent variables: *structure* is either the concave or convex bend. Participants are dragging in a specific *direction*, either up or down across the respective bend, and are identifying a specific *position*: start, peak or end of the bend (Figure 4). First, a starting point was shown above or below the respective bend on the screen. As soon as participants touched it, they were asked to look straight ahead where the current direction (up, down) and target position (start, peak or end) were displayed. Then, they had to move their finger to the respective point, lift the finger and hit a button on a keyboard in

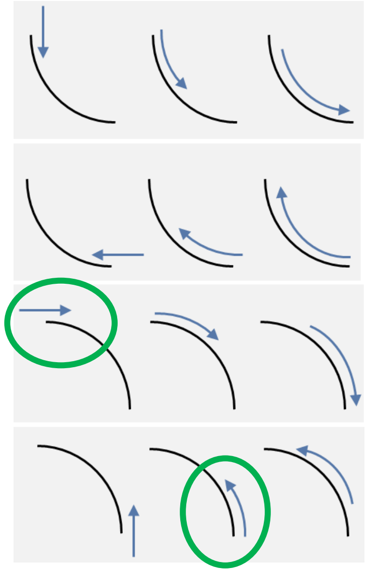

Figure 4. Dragging tasks towards start, peak and end point of a curvature. From top to bottom: Down on concave bend. Up on concave bend. Down on convex bend. Up on convex bend. Highlighted: the two combinations with the lowest mean vertical deviation.

front of them. The study setting was similar to the first study, participants were told to picture the screen as a center console and themselves in the driver seat. The order of trials was counterbalanced using a Latin square, with two runs of which only the second was used for analysis due to learning effects. 12 participants (6 female, mean age of 25) took part in the study.

Overall, peaks were recognized fastest and with the best subjective rating as opposed to start and end positions of the bends. Most of the time, participants did not overshoot the intended position but stopped without correcting backwards, indicating that they quickly got a good impression of the quantity of the bends. The two combinations that were recognized with the lowest vertical deviation, i.e. participants did not stop with their finger far before or after the actual position, were dragging down on start of the convex bend, and when dragging up on the peak of the convex bend (Figure 4). We had expected the concave peak to be easily recognized, as the finger is “stopped” by the plane behind the bend. However, objective and subjective ratings did not coincide. Subjectively, participants recognized the concave peak up- and downwards with most confidence.

There was no significant objective difference between dragging *directions* across the bend. Subjectively, regarding performance, speed and preference, participants clearly preferred the down movement. Another interesting finding is the horizontal deviation, which differs significantly between dragging up and down. Starting at the top caused the end point to be shifted to the right, while dragging up shifted participants’ fingers to the left. This might be due to the arm’s circular movement around the shoulder, and should be considered when designing dragging tasks.

Conclusion and future work

In our first use case, we could show that structure, especially convex bent curves, can ease interaction such as dragging by providing haptic guidance. The second use case gave an example for an interaction that uses the specific properties of a structure, namely different sections of a curve, to identify trigger points for an application. We think that the conducted studies are a starting point for further investigating the properties of non-flat displays to improve touch interaction and reduce the required visual attention. This can help whenever visual attention is required elsewhere, e.g. while driving, but it can also increase accuracy and subjective comfort. Different structures might support different functionality [5] so the next step should be to investigate different manifestations of non-flat displays and derive design guidelines to support existing or new ways of touch interaction.

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