The Pie Slider: Combining Advantages of the Real and the Virtual Space

Alexander Kulik, André Kunert, Christopher Lux, and Bernd Fröhlich

Bauhaus-Universität Weimar,
{alexander.kulik,andre.kunert,bernd.froehlich}@medien.uni-weimar.de}
http://www.uni-weimar.de/medien/vr

Abstract. The Pie Segment Slider is a novel parameter control interface combining the advantages of tangible input with the customizability of a graphical interface representation. The physical part of the interface consists of a round touchpad, which serves as an appropriate sensor for manipulating ring-shaped sliders arranged around a virtual object. The novel interface concept allows to shift a substantial amount of interaction task time from task preparation to its exploratory execution. Our user study compared the task performance of the novel interface to a common touchpad-operated GUI and examined the task sequences of both solutions. The results confirm the benefits of exploiting tangible input and proprioception for operating graphical user interface elements.

Key words: Menu Interaction, Circular Menu, Continuous Values

1 Introduction

A tangible representation of digital information can help users to understand and operate complex systems. Many such interfaces deal with the spatial manipulation of virtual objects, which are directly and intuitively controlled through physical representations (e. g. [22], [21], [7], [10], [8]). However, if it comes to the control of abstract parameters (e. g. sound, colors or system parameters) exploiting the benefits of tangible interaction techniques is not as straightforward. For abstract parameters, users find it often difficult to directly specify a desired value on a scale without adjusting it and perceiving the result. We argue that appropriate control interfaces should therefore emphasize on direct manipulation of a parameter value rather than on targeted selection.

We developed the Pie Slider interface (fig 1) to combine the benefits of tangible interaction (namely tactile constraints and proprioception) with those of graphical representations (namely customizability and definable range) for efficient manipulation of varying parameter sets. The design of our novel interfaces is strongly influenced by the observation that workflows in complex applications do not only involve the manipulation of parameters, but an important amount of time is also spent on preparations (e. g. tool selection). With the development

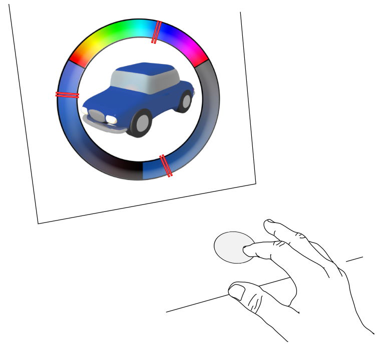


Fig. 1: The Pie Slider for color adjustments.

of the Pie Slider we aimed at reducing the required time for the selection of parameters and emphasize on the actual manipulation of their respective values.

The design is based on two major principles:

1. The design of the graphical interface and the tangible input sensor resemble each other as such that the user can control the system without looking at the input device.
2. The starting point for input on the device's surface defines the parameter to adjust, while the relative motion of the finger on the surface changes its value.

Our work contributes to research regarding the exploitation of tangible constraints for supporting the user's input as well as circular menu systems and sliders. To evaluate the usability of the Pie Slider interface we performed a controlled user study. The results confirm the benefits of exploiting real world references such as tangible devices and proprioception for operating graphical user interface elements.

2 Tangible Constraints

Ullmer et al. [20] introduced the concept of core tangibles to facilitate menu interaction and parameter adjustments using tangible interfaces for various applications. They use physical menu cards (t-menus) for the association of digital content with interaction trays, which contain sensor electronics for the selection and manipulation of items and parameters depicted on the t-menus. Labels for tangible interaction devices may also dynamically change. Kok and van Liere [13] used an augmented reality setup to analyze the impact of passive tactile feedback as well as the co-location of input action and visual representation on interaction performance. They demonstrate significant benefits for both independent variables in experimental tasks consisting of menu selection and slider adjustments. TUISTER [2] and DataTiles [18] are two other examples of a tangible user interfaces that allow to dynamically exchange the data reference of the tangible device. The concept of data tiles also includes specific parameter tiles for a visual representation of linear or circular sliders. They carry tactile grooves for providing passive tactile feedback for the constraints of the respective interface.

Parameter adjustment by circular sliders in combination with passive haptic feedback provided by a physical input device can be also found in the watch computer interaction system of Blaskó and Feiner [1] as well as in some commodity computer devices like the iPod^{TM} scroll wheel. Empirical comparison of such touch-based interfaces with tactile guidance to physical scroll wheels [24] and jog dials [15] revealed that the semi-tangible approach is not necessarily worse in terms of task performance. The touch sensitive scroll ring even showed advantages over the physical scroll wheel in a document scrolling task, since clutching was not required and thus large distances were covered more efficiently [24].

3 Selection and Adjustments

PieMenus [11] and marking menus [14] are prominent examples of circular selection layouts and their advantages with respect to certain workflows in human computer interfaces have been demonstrated [3]. Circular gestures allow for continuous position-controlled input without requiring clutching [19], [16] and they provide a very intuitive and efficient way to adjust the motion velocity. FlowMenus, introduced by Guimbretière et al. [9], incorporate an attempt to combine circular menu layouts with rotational adjustments of parameters. They allow the user to select a parameter from a circular menu, which can then be adjusted with circular motion input in a fluent gesture. Such a combination of parameter selection and adjustment can also be found in control menus [17], where the parameter's value is not adjusted with circular, but with linear motion input. However, McGuffin et al. reported that users were having difficulties in adjusting continuous parameters with both techniques, which did not make use of the tangible qualities of the employed input devices. The authors propose another integration of circular parameter selection and subsequent adjustments, which they call FaST sliders. Here users adjust linear sliders that appear after the selection of a parameter from a circular marking menu.

4 The Pie Slider

Previous research has demonstrated the efficiency of circular touchwheels for scrolling tasks [24], [15]. This interaction method may also be applied for the adjustment of other, more abstract parameter sets influencing e. g. image or sound characteristics and thus be employed for the design of remote controls for media commodities or public displays. Adjusting the appearance of an image may require modifications in contrast, brightness and saturation. Tuning sound may involve the adjustment of volume and stereo balance or the manipulation of several bandwidth-dependent parameters. Obviously the parameters in each set should be displayed together to support adjustments of all relevant factors in a concerted fashion.

Touchwheels provide relative isotonic input. It is therefore not relevant where the user starts the circling input motion. In contrast, touch sensors report the absolute finger contact position. We propose to exploit this information for pie menu-like parameter selection. We segment the circle into as many sections as there are parameters belonging to a specific set. For example, for color manipulations in HSV color space we segment the circle into three segments (fig 1). Using a touch-sensitive device instead of a mechanical jog dial or knob allows for various segmentation configurations. Circular-shaped input devices such as a touch wheel or a circular touchpad serve as a prop for circular layouts of graphical user interfaces. To select one of the presented parameters the user simply taps into the corresponding zone of the touch device and starts adjusting its value with continuous input motions along the rim (fig 2). During the continuous finger motion the areas of the other parameters can be passed without changing the selection. Thus the parameter range can be mapped to a full 360 degrees circular motion or even to multiple physical rotations if more precision is required.

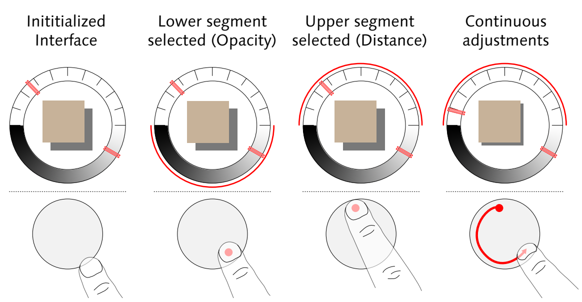


Fig. 2: Specifying a shadow effect with the Pie Slider

We decided to use a circular touchpad instead of a touchwheel because touchpads are often built into handheld devices and mobile computers for cursor control. Furthermore, the touchpad provides two degrees of freedom instead of only one available with the touchwheel. We use a polar coordinate system for operating the pie slider with a circular touchpad. The angular value controls a parameter value. The radius can be used to switch rapidly between the initial and the newly set value. Moving the fingertip back to the touchpad's center resets to the initial value, moving back to the circular border sets it again to the recent adjustment (fig 3). Thus the user can rapidly switch back and forth between both values to evaluate the effect of the recent parameter change. Lifting off the finger at the circular border confirms the newly set value while the value remains unchanged otherwise.

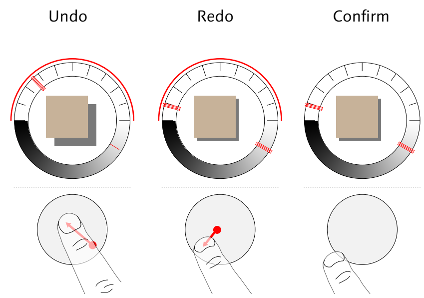


Fig. 3: undo, redo and confirmation with the Pie Slider

The basic motivation for the Pie Slider is to preserve the adaptability of virtual representations while providing just enough tangibility to facilitate efficient and precise interaction without forcing the user to visually control input actions. The circular touchpad acts as an appropriate tangible prop for operating the Pie Slider. Interaction thus benefits from proprioceptive and passive tactile feedback both for tapping on discrete selection items and for the relative circular slider adjustment by the motion of the finger along the touchpad's rim.

Circular arrangements do not only have advantages regarding the accessibility of items and the option of continuous motion, but also they can be placed around an object of interest without obscuring it (fig 1). Thus the user's focus can be kept on the object being modified rather than on a menu placed somewhere else on the screen. Webb and Kerne [23] developed the concept of in-context sliders and demonstrated the benefits of placing a slider interface within the respective object area on the screen without occluding it like pop-up menus often do. Instead of positioning the slider in an overlapping fashion within the respective object, a similar effect can be achieved with circular menus and sets of rotational sliders framing the object of interest.

5 User Study on a Color Adjustment Task

We implemented an hue-saturation-value (HSV) color adjustment task to analyze the usability and performance of the pie slider (circular condition) and compared it to the commonly used linear sliders (linear condition). The goal of the task was to match the color of a displayed square to a given color shown in an adjacent square (fig 4). The color of the upper square was directly manipulated by the user while the lower square displayed the target color. Once the color had been set correctly, the task was completed and the next trial automatically started. Only one parameter had to be adjusted at a time to minimize the influence of individual color adjustment skills. The respective slider was highlighted by a white outline. The other two parameter sliders remained operational, but in case of mis-activation, the input was reset after lifting up the finger.

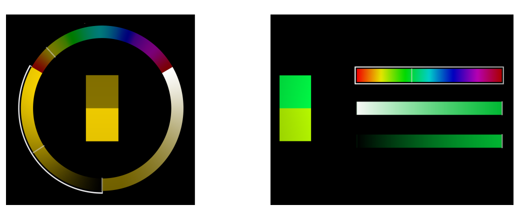
During the circular condition the screen displayed the three HSV controls as equally distributed ring segments with hue at the top, saturation at the lower right and value assigned to the lower left sector (fig 4a). For the linear condition, the controls were horizontally stacked with hue on top, saturation in the middle and value at the bottom (fig 4b). All sliders incorporated a wiper or handle, indicating the current setting.

We assured that the related variables including the size and appearance of the visual interface and the tolerance of setting were comparable across both input conditions. With respect to the input motion requirements, this was not always possible, but we tried to balance them by adjusting lengths and distances for the linear slider condition to corresponding length and distances along the circular perimeter for the circular condition.

The Pie Slider enabled direct parameter selection through finger contact in the corresponding zone of the touch device. After selection, this parameter could be manipulated by circular motion. Lifting the finger off from the touchpad completed an adjustment. The linear condition provided the same functionalities, but in a different way. Common linear sliders had to be manipulated by a cursor. The wiper could be selected using the cursor and dragged to the target position. Moving the pointer off the slider area did not result in losing the connection to the wiper.

As a shortcut method in the linear condition, the slider could be selected at a specific position by directly pointing at it, which caused the wiper to jump to the selected value. Since the slider controls in the experimental application visually represented their parameter space, the users could directly aim at the desired value and then drag the wiper only if fine adjustments were necessary. This interaction method may be more efficient in cases where the target value is known beforehand as in our test scenario. In many real world applications this approach is not as helpful, since adjusting values is more often an exploratory task in which users actually want to visually track the continuous changes between a sequence of values.

Besides the control technique, we included further independent variables in the studies, namely the type of color parameter that had to be adjusted and the distance between the starting and the target value. We expected differences in the cognitive effort to adjust hue, saturation or value resulting in an impact on task completion times. For the variable *distance*, we defined five conditions based on a linear relation to the index of difficulty as defined by Fitts' Law[6].



(a) Circular Sliders (b) Linear Sliders

Fig. 4: Slider Menu for HSV Color Adjustment

5.1 Task Modeling

We modeled the color adjustment task for the linear and circular condition using the Keystroke Level Model [4] to predict task execution times for common desktop interfaces. We expected mental operations for task initialization as well as for visual attention shifts.

For the Pie Slider we identified the following sequence of operations:

1. M_{init}: Mental operation to initialize the task
2. K_{select}: Segment selection as an equivalent to a Keystroke
3. A_{adjust}: Circular dragging operation for adjustment
4. $B_{confirm}$: Button or touchpad release for confirmation

This leads to the following equation:

$$T_{circular} = T_M + T_K + T_A + T_B \quad (1)$$

For the linear slider condition we identified the following sequence:

1. M_{init}: Mental operation to initialize the task
2. M_{search}: Mental operation to identify the pointing target
3. P_{select}: Coarse pointing to the desired value
4. B_{pick}: Press button to drag wiper
5. A_{drag}: Linear dragging operation for adjustment
6. $B_{release}$: Button release to confirm action

Leading to the following equation:

$$T_{linear} = T_M + T_M + T_P + T_B + T_A + T_B \quad (2)$$

Based on this model we assumed that using the Pie Slider would be more efficient due to simplified parameter selection. We wanted to evaluate this model and get insights into the influence of the apparatus used to perform the modeled task sequences. To compare the recorded execution times of our study with the predicted task sequences, we distinguished the selection phase and the adjustment phase of the task. We used touchpad or button contact events as a trigger to distinguish the two phases. Note that within the linear condition the color adjustment could be partially or fully achieved during the *selection* phase by directly pointing into the proximity of the target value. Selection and adjustment operations of incorrect parameter controls were logged separately in order to compare the likelihood of making errors with each interface and to get more accurate data on the time distribution among task sequences.

5.2 User Study

Experimental Setup The study was conducted on a desktop set-up using a 30” LCD graphics display for visual stimuli. The visual control interfaces of both *techniques* stretched over 30 cm (in length or diameter) on the screen. The participants were seated at approximately 1m distance to the screen and we asked them to place the input device on the table such that they felt comfortable. Both conditions were based on touchpad-based input. The employed sensor device provided an active area of 62.5mm x 46.5mm. In the linear condition the touchpad operated the cursor, while in the circular condition, the device served as a tangible reference to the displayed parameter set. Here the touch-sensitive area was covered by a 2mm strong plastic plate leaving a circular area of 44mm in diameter unmasked for touch input. Thus the linear condition was operated with relative motion input for selection as well as slider adjustments, whereas the circular condition exploited absolute position input for selection and relative motion input for adjustments. To balance precision and rapidity, a non-linear transfer function as known from pointer acceleration in operating systems was applied to motion input in both conditions.

Participants Six female and ten male users aged between 20 and 33 years participated in this study. All of them were students in engineering, fine arts or humanities. None of them reported to have issues with color perception.

Design and Procedure First, our participants were introduced to the devices and interaction techniques used in the study. Then they were given a training session to learn procedures of the color adjustment task in both menu conditions. After a short break 75 color adjustment tasks were recorded for the first menu type, followed by another 75 with the other one. The order of the *technique* conditions was balanced between users. To minimize fatigue every 15 subsequent trials short breaks were detained. One sequence included each of the three color parameters combined with five distance conditions respectively. To assure that color differences could easily be distinguished we applied a tolerance level of 4% and conducted pilot studies to specify color values for start and target that are perceptionally easy to identify. The predefined values were listed in a database and randomly presented to the participants, while assuring that no specific color adjustment task was repeated.

Hypothesis We estimated the average time required for task execution with the pie slider (3) and the linear sliders (4) by using the execution time predictions (in seconds) provided by Card et al. [5] as well as John and Kieras [12]:

$$T = 1.35 + 0.28 + T_A + 0.1 = 1.73 + T_A \tag{3}$$

$$T = 1.35 + 1.35 + 1.1 + 0.1 + T_A + 0.1 = 4.00 + T_A \tag{4}$$

The required time for color adjustment (T_A) could not be obtained from the literature. Even though on the motor level it is a simple dragging operation, we expect longer execution times due to cognitive load. In both conditions slider adjustments were controlled with relative motion input and a comparable control display gain. But while the distance between start and target value could only be covered with slider motion (T_A) in the circular condition, the linear condition enabled to shorten this distance by pointing close to the respective target value on the slider. In this case T_A can become zero if the user points very accurately. However, we assumed that cognitive processes of comparing two colors have a higher impact on operation times than the distance. Hence we based our hypotheses on the assumption that adjustment operations will require a comparable amount of time in both conditions.

- H1: The time required for the selection operation will be significantly longer for the linear condition.
- H2: The times for the selection subtask will contribute the main differences in task completion times.
- H3: The Pie Slider will perform significantly faster for the color adjustment task than the linear sliders.
- H4: *Distance* will have a stronger impact on task completion times for the circular condition.

5.3 Results and Discussion

Data was collapsed and entered into a 2 (technique) x 3 (parameter) x 5 (distance) analysis of variance with the order of techniques as between-subjects factor. Order of techniques showed no main or interaction effect. Bonferroni adjustment of α was used for post-hoc comparisons. We found significant main effects on task completion times for the factors *technique* ($F(1, 14) = 5.26$, $p < .05$) and *parameter* ($F(2, 28) = 4.02$, $p < .05$) as well as a significant interaction between *technique* and *distance* ($F_{(4,56)} = 3.46$, $p < .05$).

Task completion times were significantly shorter for the circular condition (5.12 s) than for the stack of linear sliders (5.74 s), which confirms H3. A closer examination of the task phases (fig 5) shows that parameter selection took 75% less time in the circular condition (0.67 s) than in the linear condition (2.75 s), which confirms H1. In both cases the selection time is much shorter than expected. We suggest that the task did not require the expected time for initialization, because the users were repeatedly performing it. When subtracting the expected 1.35 s for this mental operation, the predicted values get close to the recorded data. The average time for the adjustment operation was 3.34 s in the circular and 2.84 s in the linear condition. The time advantage of the linear condition may result from differences in the involved motor operations. However, since users were provided with information on the target value, it is more likely that it stems from the described possibility of pointing close to the target value during the selection phase.

The results indicate that the performance advantages of the circular condition mainly stem from the facilitated selection process, but we cannot see the huge advantage (summing up to 1.58 s) in the overall task completion times. This is due to the differences in the errors. The sum of incorrect selection and adjustment time is much higher for the circular condition than for the slider condition (1.26 s vs. 0.17 s). We observed that the benefit of a facilitated selection process comes with the drawback of a higher likelihood of incorrect selections.

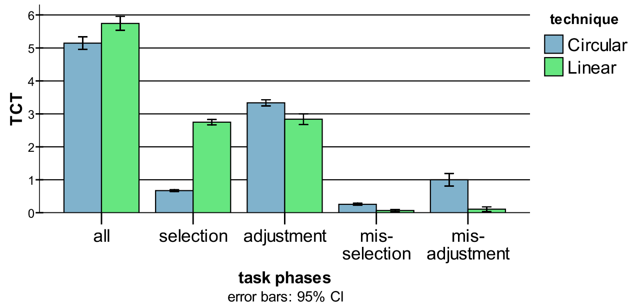


Fig. 5: Task phases per menu type

The task completion times for hue, saturation and value are 5.72 s, 5.43 s and 5.14 s, respectively. Post-hoc comparisons showed a significant difference ($p < .05$) only between hue and value, which indicates a higher cognitive effort to adjust hue. The parameter hue consisted of several color ramps between the primary colors, whereas the control of value can be intuitively mapped to the one-dimensional ("more or less") scale of a slider.

A closer analysis of the interaction of *technique* with *distance* does not support H4. Task completion times for the circular condition does not consistently increase over the five distance values (5.03 s, 4.92 s, 5 s, 5.07 s, 5.59 s - from short to long distances), but only with the largest distance. However, the task completion times recorded in the linear condition expose a variation that seems to have even less correlation with distance (5.45 s, 6.08 s, 6.02 s, 5.48 s, 5.69 s – from short to long distances).

In summary we found that the participants of our study rapidly became proficient in operating our novel parameter control interface. The performance of the Pie Slider interface was significantly better than the performance of the commonly used interaction technique for manipulating virtual controls on the screen. We observed that direct pointing on a tangible device is more efficient than screen-based interaction with virtual tools - even though the on-screen targets were much larger in our study than in common graphical user interfaces.

6 Conclusions and Future Work

The Pie Slider facilitates the rapid selection of the parameter to be adjusted and allows users to spend most of the interaction time on its actual parameter adjustment. Our approach combines advantages of tangible control devices such as proprioception and tactile guidance with those of graphical user interfaces including scalability and dynamic labeling. The comparison of the Pie Slider to the common linear slider interface showed the overall usability of the developed approach for the adjustment of parameter sets. We observed that users rapidly become proficient with the hybrid interaction technique consisting of absolute point selection and relative motion input. Significant performance benefits were found for absolute pointing within the tangible reference frame of the circular touchpad. However, we also observed that such accelerated interaction techniques do not only facilitate intended operations, but also unintented ones.

Our aim to shift interaction time from the preparation of the task to its operation could be achieved with the design of the Pie Slider. Our results prove that even in tasks where the target value is known beforehand the novel interface is competitive to common approaches providing the possibility for directly selecting a target value. We suggest that in cases, where the desired value is not known beforehand, but needs to be explored through continuous manipulation, the Pie Slider would show even stronger performance advantages.

We believe that the presented interaction technique is beneficial for many applications that require the adjustment of abstract parameters. The inherent adaptability of the interface suggests a generic implementation for indirect interaction on various display systems including home entertainment and presentation displays for advertisement or data visualization. Besides integrating the novel parameter control technique into such applications, we will further develop and analyze interaction techniques that facilitate task preparation and emphasize on the exploratory adjustment of parameter values.

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