DISTANCE-ADAPTED 2D MANIPULATION TECHNIQUES FOR LARGE HIGH-RESOLUTION DISPLAY ENVIRONMENTS

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Abstract: Physical navigation presents an intuitive overview+detail technique in large high-resolution display environments where users interact at different distances. Thus, the user interaction should be adapted to the user's current position. This ongoing work presents bimanual interaction techniques that use distance-adapted mapping of physical hands motion to virtual relative objects motion (named interaction scaling). Interaction scaling allows the user to manipulate high-resolution content with the appropriate accuracy at diverse distances. In our initial experiment, we considered two relative mapping functions: continuous mapping and zone mapping. The mapping functions manipulate the 2D position of the virtual cursor. The parameters for the 2D manipulation tasks (i.e., scaling, rotation, translation) are calculated from the virtual cursor behavior. We developed two bimanual interaction techniques for 2D object manipulation that support the interaction scaling: separated-cursors and connected-cursors method. The separated-cursors technique differentiates the users hands between dominant hand and nondominant hand. The connected-cursors technique uses an additional midpoint cursor that is located between both virtual cursors. In an explorative study we evaluated the separated-cursors technique with and without interaction scaling. An interesting result is that the participants often needed less object selections to sort objects with interaction scaling compared to the scenario without interaction scaling.

1 INTRODUCTION

Large high-resolution displays (LHRD) combine a large physical display area with high pixel density. On the one hand LHRDs allow users to perceive the global context of complex information by simply stepping away. On the other hand the users are able to step closer to the display to see detailed information. In this context, interaction techniques for LHRDs should support mobility, accuracy and easy availability to carry out interaction tasks.

The interaction techniques described in this paper are developed in the context of our Tele-Presence System comprising a 24-panel LCD wall (Willert et al., 2010). The setting allows us to display remote users at a natural scale, at a sufficient resolution, and to share interactive high-resolution content. For collaboration work, a shared virtual space with variable depth is located between the local and remote user.

For this environment we require intuitive user interaction that supports the large interaction volume in front of the LCD wall. The user should be able to carry out distant selection and manipulation as well as manipulation with high precision at close range.

In general the user's distance in front of a large display is considered for selection and navigation tasks in previous work (Kopper et al., 2010; Peck et al., 2009; Vogel and Balakrishnan, 2005).

In our ongoing work we investigate how the user benefits from the user–display distance for simple 2D manipulation tasks. The main contribution of our work is the interaction scaling approach that allows the user to manipulate 2D objects with the appropriate accuracy in varying distance.

We developed two bimanual interaction techniques for 2D object manipulation: *separated-cursors* and *connected-cursors* method. In an explorative study, we evaluated one distance-adapted 2D manipulation technique (separated-cursors) with two mapping functions, which map the physical absolute hands motion to virtual relative objects motion.

2 RELATED WORK

In large high-resolution display environments interaction techniques have to be customized that the user is able to interact with virtual content from various dis-

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tances.

For instance, extended laser pointer techniques allow the user to interact with (physically) unreachable objects and small objects in large display environments (Peck, 2001; Ahlborn et al., 2005; Argelaguet and Andujar, 2009; Fukazawa et al., 2010). Ahlborn et al. (Ahlborn et al., 2005) have developed an effective detection algorithm of laser pointer interaction on large-scale display environments that works at various lighting conditions. Using a predictive searching reduces the amount of image processing to detect the laser pointer dot. Using infrared laser pointer techniques (Cheng and Pulo, 2003; König et al., 2007) the on-screen cursor is invisible, thus the problem of hand jitter and latency are hidden from the user. Those techniques use a visual representation of the invisible laser dot (e.g., hotspot, visual cursor). Vogel and Balakrishnan (Vogel and Balakrishnan, 2005) investigated techniques for pointing and clicking using only the user's hand. For example, they developed a hybrid pointing technique that uses ray casting for coarse pointing interaction and relative pointing for more precise interaction.

Another challenge is the manipulation of virtual objects on large workspaces. In (Collomb et al., 2005) dragging techniques use an acceleration method to overcome large distances. Grossmann et al. (Grossman et al., 2001) provide a two-handed interaction technique for the creation of 3D models by drawing 2D profile curves on large displays. In (Jeon et al., 2010) camera-equipped mobile phones are utilized by the users to interact with large displays. The virtual objects have been manipulated based on the motion gestures that are performed by the user with his mobile phone. The CGLXTouch project (Ponto et al., 2011) supports multitouch device interaction by multiple users. A low-resolution screen image of the display wall is displayed on the multitouch device corresponding to the available pixel resolution of the device. Thus, users can indirectly manipulate data on the ultra-high-resolution display via multitouch gestures on their devices concurrently.

Previous work (Jota et al., 2009; Kopper et al., 2010; Peck et al., 2009; Vogel and Balakrishnan, 2005) has shown that the current distance of a user to a large display affects the usability and the user's performance. For example, when stepping closer to LHRDs it is helpful to refine the selection radius or to adjust the navigation speed. In (Kopper et al., 2008) the user is able to switch between absolute and relative mapping for pointing interaction. Furthermore, the user can control a zoom window. It provides a magnified view of objects, where the user can precisely interact. Multiscale interaction by Peck et al. (Peck et al., 2009) is a 3D interaction technique that uses the benefit of physical navigation in front of a large high-resolution display. Depending on the user's distance from the interaction object, he controls the scale of interaction in addition to the scale of perception. For example, when the user changes his physical position relative to the display, the multiscale cursor is changed, which rescales the data on the display interactively. The interactive public ambient display (Vogel and Balakrishnan, 2004) utilizes the user distance to control public and personal information presentation. In (Shoemaker et al., 2010) the user distance controls the virtual light-source position that affects the interactive user's shadow cast.

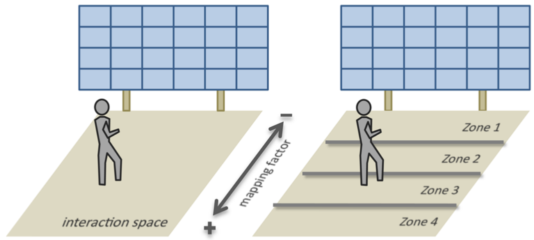

Figure 1: Interaction scaling with a) continuous mapping (left) and b) zone mapping (right).

Our objective is to find a general approach for scalable interaction that adjusts the interaction precision to the user's position in front of a large high-resolution display.

3 INTERACTION SCALING

Interaction scaling means to adjust the technical precision of user interaction depending on the user's distance to the LHRD. Our objective is to find an adequate mapping of the user's movements to virtual movements. Interaction scaling allows the user to manipulate high-resolution content with the appropriate accuracy in varying distance.

We propose a customized mapping of the gesture to the virtual cursor movements taking into consideration the user's distance to the LHRD. The current distance is calculated using the average of the distance of both hands. For example, if the user stands farther away from the display he should be able to move an object across a large LCD wall with a small gesture. In contrast, if he steps closer to the display, the virtual object should be moved with high accuracy by using large physical movements.

In our initial experiment, we consider two relative mapping functions: continuous mapping and zone mapping. The mapping functions are applied to the

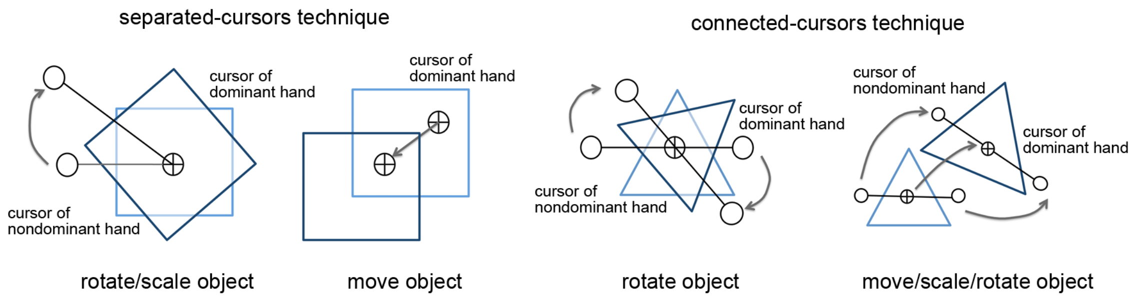

Figure 2: Interaction techniques: a) separated-cursors (left), b) connected-cursors (right). The crosshair cursor indicates the selected object.

virtual cursors as visual representation of the user's hand.

The *continuous mapping function* applies a linear factor to the physical movements. The mapping factor is equal to one at middle distance of the interaction space. The factor decreases linearly closer to the LHRD and grows linearly with increasing distance (see Figure 1, left). We use a simple linear equation to calculate the mapping factor (mf) depending on the current user–display distance (udd); m and b are designate constants:

$$mf = f(udd) = m\,udd + b$$

For *zone mapping* we divide the interaction space in front of the LHRD into four regions with predefined mapping factors: close-up range, mid-range, distant and farther region. With zone mapping the mapping factor is increased in each region away from the display (see Figure 1, right). There is no distance where the physical movements are equal to virtual movements as opposed to continuous mapping. In the first two regions the mapping factor is less than one. In these regions the user is able to manipulate objects precisely. In the other two regions the user handles object with coarse precision. Here, the mapping factor is greater than one.

Interaction scaling just manipulates the 2D position of the virtual cursor. The distance-related mapping factor is multiplied by the absolute hand position to determine the corresponding virtual cursor position. The parameters for the manipulation tasks (i.e., scaling, rotation, translation) are calculated by the virtual cursors behavior. Thus, the mapping factor influences the precision of the manipulation indirectly. Similar to common two finger multitouch gestures, the scaling factor is calculated based on the distance change between both cursors. The rotation angle is computed from the angular rotation of the line between both cursors.

We developed two bimanual interaction techniques for 2D object manipulation that support the interaction scaling: *separated-cursors* and *connected-cursors*. We use tracked wireless input devices with multiple buttons to simplify the triggering of user interaction. Thus, the user is able to point at an object, push the button to start the interaction, and release the button to complete the interaction.

The *separated-cursors* technique differentiates the user's hands between dominant and nondominant hand. The dominant hand is used to select and translate an object. The nondominant hand is used to scale and rotate the selected object (see Figure 3, left). During scale/rotate mode the dominant hand's virtual cursor is fixed and the corresponding hand motion is ignored. The object manipulation is illustrated in Figure 2 (left).

The *connected-cursors* technique uses an additional midpoint cursor that is located between both virtual cursors (see Figure 2, right). This midpoint cursor is used to select an object. In order to translate a selected object the virtual cursors have to move to the desired direction simultaneously. Increasing or decreasing the distance between the cursors resizes a virtual object. To rotate an object the user moves his hands in a fashion similar to turning a steering wheel. The connected-cursors method allows the user to select and manipulate a virtual object in a continuous manner without changing the interaction mode. The manipulation tasks are performed simultaneously.

4 EXPLORATORY STUDY

We conducted an experiment to evaluate our interaction scaling techniques for LHRDs. Our hypothesis is that interaction scaling improves the user performance compared to manipulation tasks that do not exploit the current user distance to the large display wall.

In an explorative study, we investigate one interaction technique (separated-cursors) with two mapping functions of interaction scaling (continuous mapping,

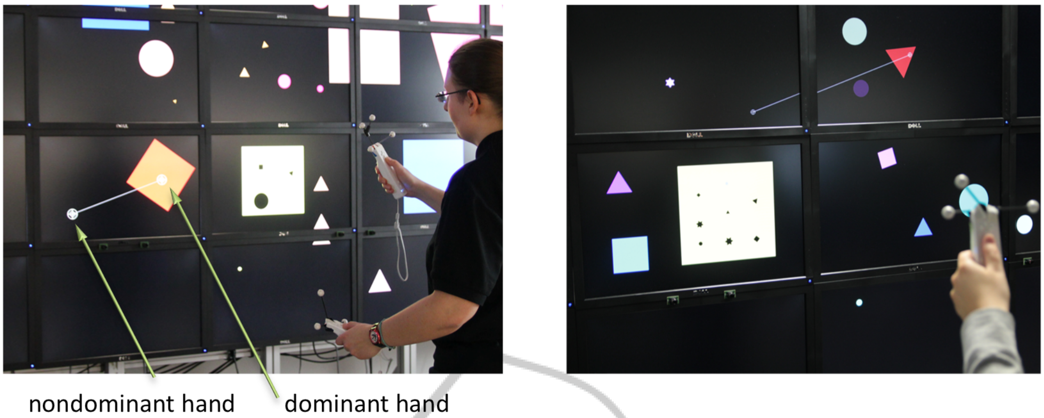

Figure 3: Application with separated-cursors technique: the differentiation of user's hands (left) and the target box of the experiment (right).

zone mapping), as described in Section 3. The primary function of this study is to discover parameters, which affect the application of interaction scaling for 2D manipulation tasks. Using these results we are able to develop a suitable interaction scaling depending on the LHRD setup and manipulation task in order to improve the user performance.

In the study, we would like to evaluate just one interaction technique to reduce the duration of an experiment for each participant. After initial tests, we expect that the separated-cursors technique provides promising results.

We implemented a 2D puzzle solver application to compare the task completion time and the number of object selection with and without interaction scaling. We use OpenGL for rendering and the Vrui toolkit for device and display handling[1].

4.1 Apparatus

We use a flat tiled LCD wall consisting of 24 DELL 2709W displays, where each tile has a resolution of 1920 x 1200 pixels, with a total resolution of 11520 x 4800 (55 million pixels). In front of the display wall the interaction space is approximately 3.7 x 2.0 x 3.5 meter. The user holds a Nintendo Wii Remote in each hand to interact with the application. We use an infrared tracking system (Naturalpoint OptiTrack TrackingTools) with 12 cameras arranged semicircularly around the LCD wall. The current user–display distance is calculated by the average of the distance of both tracked input devices.

Pointing gesture allows an intuitive interaction with virtual objects at different distances. In order to simplify future tracking the hands position are tracked only in front of the LHRD and we do not consider the orientation of the hands or input devices. Therefore, 3D position detection is quite possible by various optical tracking methods. The hands' positions are projected orthogonally on the screen.

After a while a drift arises between absolute hand motion and relative cursor movements by using interaction scaling. Since the mapping factor is multiplied by the absolute hand position to determine the virtual relative cursor position. For this reason, the user can trigger a reset of the virtual cursors position corresponding to the hands position.

Since we use an LCD wall with bezels, the puzzle application is configured in such a way that no virtual content is occluded by the bezels. The virtual objects are limited by a minimum and maximum size (range size 1cm–50cm). The size limits were determined experimentally and the virtual objects are visible at distance. The virtual objects are generated with random size and position at application start without overlapping. The target objects will always be in the same place on the display and be of the same size. The tracking system setup restricts the user interaction distance from 40 centimeters to 3 meters.

There are two interaction scaling scenarios: continuous mapping and zone mapping. Continuous mapping calculates a mapping factor that increases from 0.2 to 2.5 with increasing distance. The zone mapping scenario divides the interaction space into four even regions with a depth of 50 centimeters. The experimental mapping factors are 0.2 (close-up range), 0.7 (mid-range), 1.5 (distant region), and 2.5 (farther region). If the user moves his hand ten centimeters in physical space at close-up range then the corresponding cursor is moved three centimeters in virtual space. Conversely, the virtual cursor is moved 25 centimeters while the physical hand movement is

[1]http://idav.ucdavis.edu/∼okreylos/ResDev/Vrui/index.html

ten centimeters at farther region. For the purpose of comparison the scenario without interaction scaling maps the real hands movement directly to the virtual cursors motion.

4.2 Procedure and Design

The experiment consists of two parts - a training phase and the test scenarios. At the beginning the subject performs a 10 minutes tutorial to practice the interaction tasks with and without interaction scaling. Afterwards the evaluation starts. The task is to sort eight objects (a couple of triangles, circles, squares, and stars) in the corresponding targets (see Figure 3, right). In the tutorial the subject sorts three various object types. The objects position, size and orientation are randomized. The objects have to be manipulated to fit into the targets by dragging, scaling and rotating. Only when the user drops down the object onto the desired target by releasing the selection button, the application will test the fitting accuracy. The object tolerance is two millimeters regarding target size, position and orientation. Object orientation is described by the position of the vertices. The tolerance value was determined experimentally in order that users are able to sort objects without frustrating. If an object is sorted correctly, it will be locked to avoid undesired movements.

The trial starts with the first object selection, and finishes with the last sorted object. The experimental software measures the task completion time in seconds and the number of object selections. After the test, the subject fills in a subjective questionnaire.

We used a within-subject design. The independent variable was the interaction scaling with three levels (without mapping, continuous mapping, zone mapping). The presentation order was counter-balanced. Each participant performed three scenarios with two repetitions. The dependent variable was the task completion time and the number of object selections. The subject was informed whether interaction scaling is active or not.

The explorative study includes 15 participants but the test results of two persons were incomplete. Thus, we can only evaluate the results of 13 subjects. All 13 participants were volunteers that were college students (54%) or staff members (46%) from computer science department. The participants were 31% female and 69% male. The ages of the participants ranged from 20 years old to 39 years old with an average age of 27. The participants had less or no prior experience working with large display environments.

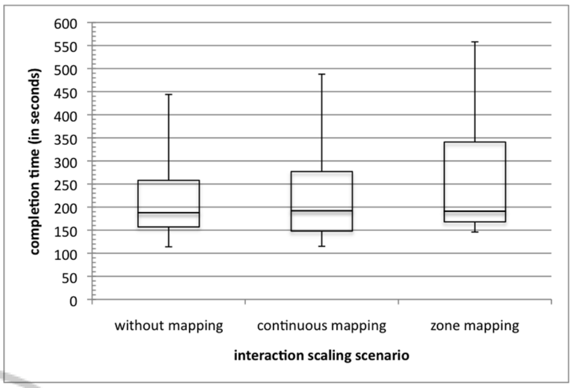

Figure 4: Boxplot of completion times within the scenarios in the first iteration.

4.3 Results

We performed a one-way ANOVA to determine statistical significance in the preliminary study. The parameter completion time shows no interesting results or no statistically significant differences between scenarios. In general, the completion time is larger at the first try to solve the puzzle. About ten participants (77%) improved their task completion time in the second run of the scenario. In the scenario without interaction scaling the mean improvement was 47 seconds and in the scenarios with interaction scaling on average 20 seconds. We observed that the presentation order of the scenarios has an influence on the completion time. The puzzle generates a low training curve. The more the participant practiced the puzzle the faster he was able to solve the puzzle without interaction scaling.

There is a correlation between task completion time and number of used object selections. An increase in completion time is combined with a larger number of selections. Sometimes the user needed more time to sort in a specific object. For instance, the subject required 14 object selections to sort in one object and then only two or five selections to sort another object in the same scenario. We observed that the completion time is a less important parameter of user performance in our experiment.

In general, the participants were faster on average without interaction scaling (mean: 209 seconds, mean deviation: 68 seconds) in comparison to the continuous mapping scenario (mean: 223 seconds, mean deviation: 85 seconds) and the zone mapping scenario (mean: 268 seconds, mean deviation: 116 seconds). The measured completion times are illustrated in Figure 4.

We identify interesting results in terms of used object selections. In particular, a difference is recog-

Table 1: Frequency of used object selections in each scenario in the first run.

scenario	without mapping		continuous mapping		zone mapping	
selections	frequency of object selections (absolute and relative values)					
1	10	9,6%	11	10,6%	11	10,6%
2	**27**	**26,0%**	**34**	**32,7%**	**31**	**29,85%**
3	16	15,4%	17	16,3%	13	12,5%
4	15	14,4%	5	4,8%	9	8,6%
5	9	8,6%	7	6,7%	9	8,6%
> 5	27	26,0%	30	28,9%	31	29,85%

Table 2: Frequency of used object selections for each object type and scenario (without mapping (wm), continuous mapping (cm), zone mapping (zm)) in the first run.

object type	squares			circles			triangles			stars		
selections	wm	cm	zm	wm	cm	zm	wm	cm	zm	wm	cm	zm
1	2	1	4	3	3	1	1	0	2	4	7	4
2	**6**	**9**	**6**	**10**	**8**	**10**	**7**	**11**	**9**	**4**	**6**	**6**
3	4	7	2	4	5	6	5	2	1	3	3	4
4	6	0	4	3	1	1	3	2	1	3	2	3
> 4	8	9	10	6	9	8	10	11	13	12	8	9

nizable between using interaction scaling and without interaction scaling in the first iteration. The number of used object selections in each scenario is shown in Figure 5. We captured 104 samples (8 objects x 13 subjects) within one run. Table 1 shows that more objects were sorted with two selections with interaction scaling by comparison without interaction scaling.

To select an object the user has to move the corresponding virtual cursor of his dominant hand onto the object and press the Wii Remote button. The user moves a selected object by moving his dominant hand. If the user presses the Wii Remote button of the nondominant hand then the scale/rotate mode is activated until the button is released. This mode allows the user to scale and rotate the selected object by moving his nondominant hand. The object is selected until the button of the dominant hand is released. However, a statistical significance between the scenarios is not present in the preliminary study.

In addition, Table 2 indicates the difference between the object types. For instance, rotatable objects (e.g., square, triangle, star) were sorted with interaction scaling (continuous mapping and zone mapping) more frequently compared to the scenario without mapping. We observed that most of subjects moved an object closer to the corresponding target at distant and then they stepped closer to the display to adjust the object. Using this strategy, the subjects needed only two selections within interaction scaling scenarios. We observed that when participants used more than five object selections they were impatient or they did not go closer to the display.

The repetitions of the scenario without interaction scaling more participants were also able to sort the objects with two selections. This suggests that object sorting without interaction scaling is a matter of practice. However, a lot of exercise is not required because the learning curve is low and finished after three solved puzzles. This observation is also reflected by the subject comments.

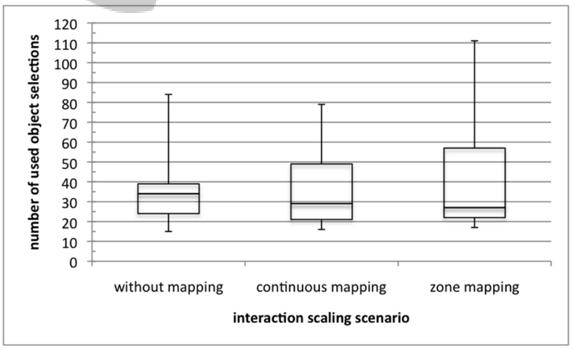

Figure 5: Boxplot of used object selections within the scenarios in the first iteration.

In the zone mapping scenario many users had difficulties solving the puzzle. The precision of the manipulation was very high in the close-up range; the participant took more physical movements to manipulate the objects. In addition, in the zone mapping scenario the precision factor changed rapidly because of the small regions. In the continuous mapping scenario the fluent adjustment was less perceived by the users.

Furthermore, we observed that the drift between hands and cursors unfavorably affects the participants. In the zone mapping scenario, the difference between absolute hand position and relative cursor position is perceptible by the user, due to the rapid changes of the mapping factor. In the continuous mapping scenario the mapping factor changes continuously. Here, the drift is less pronounced and the users are able to compensate the effect. Users with virtual reality experience were able to compensate the drift and they specifically applied the cursor reset, whereas users without experience in virtual reality environments were dissatisfied with the drift effect.

Experimental tests with a few users indicated that the completion time improves considerably by exercise with interaction scaling. Primarily, users with a natural hand tremor could benefit from interaction scaling. This idea is supported by the participants' comments. For example, eight participants preferred the scenario with interaction scaling. Some users desired to interactively disable the automatic adjustment of the precision. For instance, then the user is able to resize quickly large objects to fit into a small target at close-up range.

5 CONCLUSIONS AND FUTURE WORK

We presented distance-adapted 2D manipulation techniques that adjust the interaction precision to the user's position in front of a large high-resolution display. This interaction scaling allows the user to perform distant selection and manipulation in varying distance with the appropriate accuracy.

The introduced explorative pilot study is supposed to prepare the user study, particularly by developing and attempting the suitable interaction scaling for 2D manipulation tasks. Therefore, we evaluated the separated-cursors technique with two mapping functions of interaction scaling (continuous mapping, zone mapping) and without interaction scaling. We implemented a 2D puzzle solver application to compare the task completion time and number of used object selections.

The preliminary study shows that the users accept interaction scaling. In particular, they preferred the higher precision close to the display and the reducing of their hand tremor. The results demonstrate that the users were on average faster with continuous mapping compared to zone mapping. In addition, many participants completed the task faster without interaction scaling. One possible explanation is the short training curve of the puzzle application. The more the subjects practiced the puzzle the faster they were able to solve it.

An interesting result is that the participants needed less object selections to sort objects with interaction scaling compared to the scenario without interaction scaling. In particular, the subjects were more often able to sort objects at most two selections with interaction scaling scenarios. However, the number of used selections has shown that users required less object selections but generally they took more time to solve the puzzle with interaction scaling. Here, it needs to be checked, if more complex tasks or other tasks will improve the task completion time by using interaction scaling.

The explorative study indicates that the cursor drift strongly affects the user's performance. In particular, users without virtual reality experience were dissatisfied with the drift in the zone mapping scenario. The drift effect is less pronounced in the continuous mapping scenario than in the zone mapping scenario, because the mapping factor changes continuously and the user is able to compensate the difference between hands motion and cursors motion.

The reason we did not get statistical significant results, we suppose that the drift negatively affects the results. Thus, the drift has abolished the benefits of interaction scaling.

As future work we plan to involve intention recognition to obviate the drift between absolute hand motion and relative cursor motion. So the interaction precision is adjusted to the user's current position and his motion sequence. The drift problem occurs at both interaction techniques (separated-cursors, connected-cursors) and the available cursor reset is less intuitive. Thus, we will evaluate the connected-cursors technique with the reduced drift effect.

In our LHRD environment a maximum mapping factor of one is sufficiently good to reach objects from a distance. We expect using deeper zones; the differences between the mapping methods are clearly visible. So interaction scaling with zone mapping could improve the user's performance. Additionally we will readjust the tracking volume that the user is able to interact closer at the display. We will also test to calculate user–display distance based on the head position to adjust the precision factor as expected from the user, instead of using the average of the distance of both hands.

The next steps include utilizing the results of the explorative study (i.e., to minimize the drift, complex task, appropriate interaction zones, etc.). We will perform a user study to evaluate how the user benefits from the user–display distance for 2D manipulation tasks.

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