Investigating Haptic Assistive Interfaces for Motion-impaired Users: Force-channels and Competitive Attractive-basins

Patrick Langdon, Faustina Hwang,
Simeon Keates, P John Clarkson

University of Cambridge, Dept. of Engineering
Trumpington Street, Cambridge. CB2 1PZ
United Kingdom
Tel: +44 1223 766958

{ pml24, fh220, lsk12, pjc10}@eng.cam.ac.uk

Peter Robinson

University of Cambridge, Computer Laboratory
William Gates Building,JJ Thomson Avenue
Cambridge UK CB3 OFD
United Kingdom
Tel: +44 1223 334637

Peter.Robinson@cl.cam.ac.uk

Abstract

Following a pilot study that suggested that force-feedback gravity wells could, under certain conditions, lead to 20-50% improvements in time to target in a selection task, a series of experiments further investigated the potential for enhancement of user interfaces for disabled computer users by the use of haptic feedback modulated on the basis of cursor position. Two experiments are reported examining (1) the effect of size of attractive basins in adjacent targets on time to target in a point and click selection task and (2) the effect of presence of four different types of force-feedback channels between start point and target on times to select a target. It was found that the presence of adjacent attractive basins was not disruptive of navigation to target, and that haptic force channels may only decrease times for those with high degrees of impairment. Cursor trace analysis suggested that the increased attraction force and range counteracts the disruptive effect of inappropriate cursor capture for the overlapping basins and that inappropriate ballistic movements were suppressed by channels for some of the impaired users but that channels may have had no effect on overshoot errors in these cases.

1. Introduction

The use of force-feedback input devices to generate haptic and kinaesthesic sensations during interaction with a computer interface has been widely investigated for able-bodied interaction. For able-bodied users, tactile feedback reduces positioning times [Akamatsu, MacKenzie and Hasbroucq, 1995], while target selection has been shown to improve with the use of damping, attractive basins around targets and force feedback channels [Dennerlein, Martin and Hasser, 2000; Pledgie, Barner, Agrawal, S Rahman]. Furthermore, error rates and workload measures have been shown to be reduced in realistic GUI tasks using texture, friction and gravity wells [Oakley, McGee, Brewster, and Gray, 2000].

Following a pilot study [Langdon, Keates, Clarkson, and Robinson, 2001] that suggested that force-feedback gravity wells could, under certain conditions, lead to 20-50% improvements in time to target in a selection task, we are carrying out a series of experiments that further investigate the potential for enhancement of user interfaces for motion-impaired computer users by the use of haptic feedback modulated on the basis of cursor position. Two experiments are reported examining (1) the effect of size of attractive basins in adjacent targets on time to target in a point and click selection task and (2) the effect of presence of four different types of force-feedback channels between start point and target on times to select a target.

Experiment 1 investigates the situation where adjacent selectable targets possess attractive basins. The hypothesis tested was that the presence of adjacent attractive basins would interfere with navigation to target by competition for the cursor and that this would increase the average times to select the target with increasing diameter of the attractive basins until overlap.

Experiment 2 tested whether the use of linear force channels created using resistant walls would reduce the average times to select the target by suppressing the erratic navigation characteristic of the motion-impaired, and whether this was more effective with or without a central channel and with or without channel walls of unlimited extent.

In both experiments, a subsidiary hypothesis was that there would be significant differences between users in the extent to which the experimental manipulations affected their selection movements and that this would be dependent on the degree of their disability.

A low cost, force-feedback device marketed by the Immersion corporation (Logitech: “Wingman”, model E-UB3) was used to generate haptic interactions because of its capability for generating the *constant directional forces* that are needed to implement effects such as force-channels and attractive basins.

Cerebral Palsy, Muscular Dystrophy, spinal injuries and the after-effects of stroke, give rise to motion-impairments. These include reduced strength, restricted movement and symptoms involving spasms, tremors and motion control problems. The computer users tested represented a range of motion impairments from severe (loss of motion, severe weakness, spasm or tremor) through to mildly impaired (hand co-ordination impairment) and consisted of subsets of a small sample of 9 people predominantly representing Cerebral Palsy as well as other motion-impaired populations between the ages of 20–50 and drawn from three post-clinical vocational rehabilitation centres in Cambridge and Suffolk in the UK. These individuals were not screened for other impairments. It should be remembered that, unlike able-bodied computer users, these volunteers can experience difficulty in performing the experimental tasks. Because of these capability ‘floor’ effects, it is necessary to run the trials on a long-term basis. Also, because of the small number of users and their limited availability, repeated measures designs were generally employed. However, despite the limitations of this type of research, statistical analysis and experimental power are reported here.

1.1. Task

The experiment involved the users being presented with 16 target circles arranged equidistantly around a central circle on the screen. The aim was for the users to click on each target circle in a random order determined by the software (Figure 1), returning to the central target between each selection.

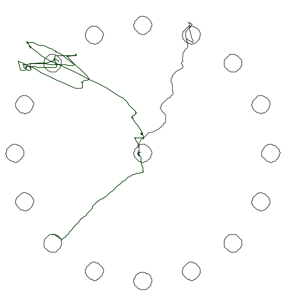

Figure 1. The selection task layout showing example cursor trajectories.

A block of trials consisted of one set of 16 random presentations. Presentation was made using a lap-top display and timing data was taken using a real-time software clock and recorded to file.

2. Experiment 1: The effect of size of attractive basin on adjacent targets

The attraction basin haptic effect corresponds to a circular region around the target that causes the cursor to become subject to a constant spring force towards the centre. There were four levels of basin radius size: 100%, 200%, 300%, 400% of the target radius. These were presented in random order as blocks of trials. Twenty blocks of trials made up a session with 5 repetitions of each level. Overlap of the basins occurred at 300% and 400%, with the amount of overlap being 9 pixels at 300% and 70 pixels at 400%.

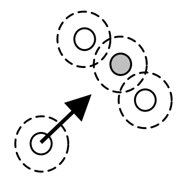

Figure 2. Start point and target showing adjacent targets and attractive basins at 400% size (not to scale).

2.1. Results

There was very little effect of the size of the attractive basin overall (ANOVA, $F(3,15)=1.86$, $p > 0.225$, $Eta^2 = 0.27$, Power = 0.226) and no significant pair-wise comparisons between sizes (Tukey HSD).

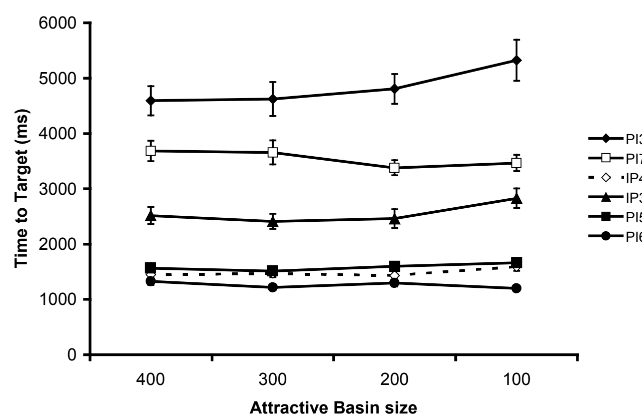

Figure 3. Time to target for 6 users and four basin sizes

An ANOVA carried out using Subjects as a factor confirmed the differences between users evident in the interaction diagram (ANOVA , $F(5,15) = 294.6$, $p <0.001$, $Eta^2 =0.99$, Power = 1.0).

2.2. Error Analysis

Examination of the distribution of errors as measured by the number of clicks to select the target confirmed that a speed accuracy trade-off did not account for the timing data. Error, measured as the number of additional clicks beyond the single click required to select the target, is shown in Figure 4 for a highly impaired individual, PI7.

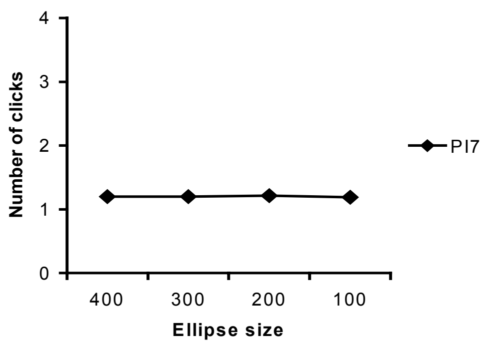

Figure 4. Average number of clicks to select the target

This indicates a random small amount of error distributed evenly over the different channel conditions.

2.3. Discussion

Contrary to the hypothesis, there was no evidence of an increase in time to target resulting from disruption to navigation caused by adjacent targets basins. However, it was observed that this disruption occurred during trials, as expected. This is illustrated by an analysis of cursor traces under the experimental conditions of both experiments presented in section 5. As the times to target for experiment 1 were unaffected between conditions when the basin lay within the target and when overlap occurred, this result suggests that increased difficulty resulting from the disruption may have been somehow offset by the increased force and range of the attraction towards the target.

The between subject analysis indicates that significant differences in performance occur as a result of the degree of impairment of the users. However, the effect of different attractive basin size appears to be non-significant over all users.

3. Experiment 2: The effects of force channels in the direction of the target

There were four channel conditions and one unassisted condition. Haptic tunnels have a channel width (i.e. distance between the tunnel's inside walls) and a wall thickness. When the cursor passes over a tunnel wall, a spring force pulls the cursor to the inside wall. Two conditions were presented with a 0 or 20 pixel channel width, and two conditions presented with either a 20 pixel tunnel wall thickness or an "unlimited" thickness.

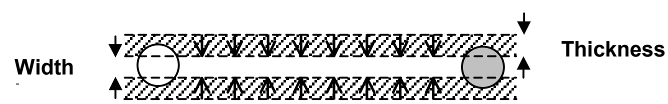

Figure 5. The relative wall thickness and channel width

Hence, with 0 pixel channel width, the cursor experienced a spring force towards the centre-line of the channel and in the unlimited wall thickness condition the spring force acted toward the centre of the channel irrespective of the cursor location, with no outer limit on the wall thickness (Figure 5). Haptic tunnels were intended to assist users in moving the cursor in a straight line to the target. It was expected that tunnels would help improve overall times to target by reducing deviations during navigation. It was hypothesised that the unlimited wall condition would prevent highly impaired users jumping beyond the channel wall, reducing times to target.

3.1. Results

There were significant differences between tunnel types overall with 36% of the variance in times accounted for by channel type. However after a Greenhouse-Geisser correction for non-sphericity in repeated measures analysis (ANOVA, $F_{(1.7,\ 10.2)} = 3.442$, $p = 0.077$, $Eta^2 = 0.365$, Power = 0.481) the difference was non-significant and reduced the observed power from 0.77 to 0.48. Despite this, corrected pair-wise comparisons (Tukey HSD) revealed a significant difference between the "No Assistance" and "Unlimited – no Channel" conditions ($p = 0.045$), and between the "Unlimited – no Channel" and "Unlimited with Channel" conditions ($p = 0.025$). An ANOVA carried out using Subjects as a factor confirmed differences between highly, medium and mildly impaired users evident in the interaction diagram (ANOVA, $F(6,24)=104.3$, $p <0.0001$, $Eta^2 =0.963$, Power = 1.0). Pair-wise comparisons (Tukey HSD) confirmed significant differences between PI3 and all others and by PI5 and PI6 and all others (all $p < 0.001$). However there were no significant differences between PI2 and HA2, and PI7 and HA1.

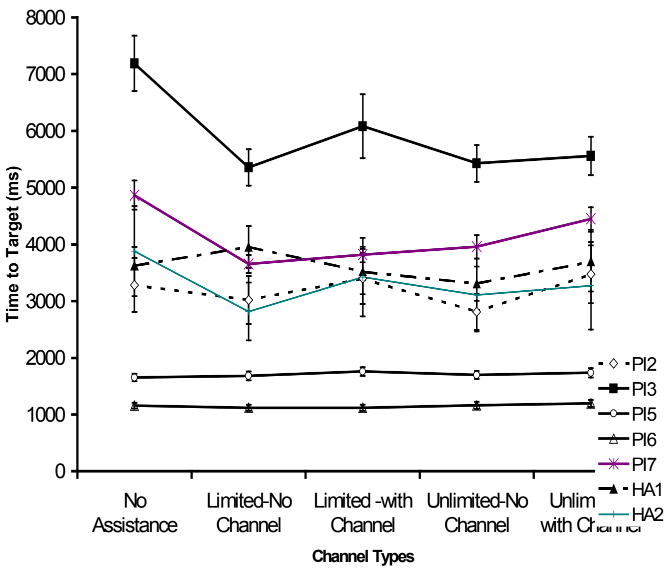

Figure 6. Mean time to target for 5 channel types

3.2. Error analysis

Examination of the distribution of errors as measured by the number of clicks to select the target confirmed that a speed accuracy trade-off did not account for the timing data. Error, as measured by the number of additional clicks beyond the single click required to select the target, is shown in Figure 7 for PI7. This indicates a random small amount of error distributed evenly over the different channel conditions.

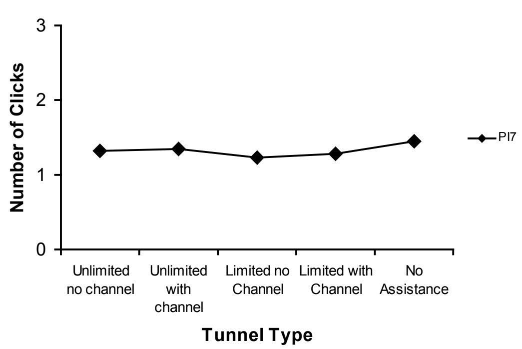

Figure 7. Average number of clicks to select the target

3.3. Discussion

There was slight evidence that the use of force channels in the direction of target was more effective than no assistance over all users. There was some evidence that the presence or absence of a central channel affected times to target indicating that constraining movement to a line was more effective than constraining movement to a tunnel. It is possible that for users experiencing difficulty navigating in a straight line, the extra freedom allowed by presence of a 20 pixel channel was a hindrance. No significant difference in times between the limited and unlimited wall thickness was observed, implying that the width of the tunnel wall does not affect performance. A possible explanation for this is that the majority of users rarely moved with sufficient force and direction to escape the tunnels.

It appears that none of the tunnels give improved times for PI2, PI5, PI6, and HA1. This may be because these users do not experience difficulty moving in straight paths. However, all tunnel types appear to be of some benefit to PI3, PI7, and HA2 who had greater difficulty navigating to the target than the other users.

4. Base-line data

Although none of the conditions in Experiment 1 were unassisted, previous average times without any form of assistance for the same task agree with those in the results for the "No Assistance" condition of Experiment 2.

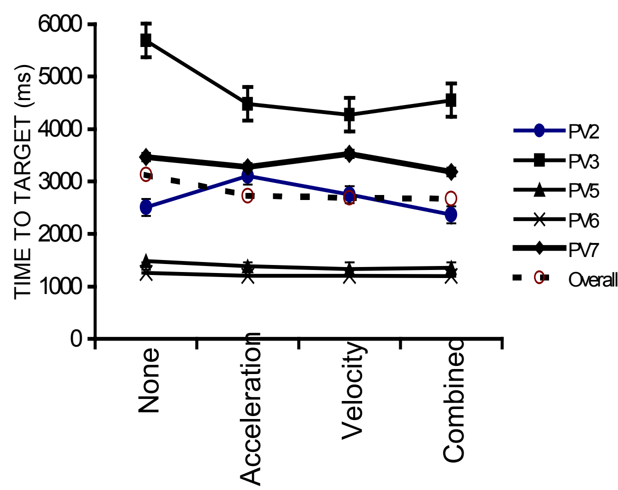

Figure 8. Base-line data for no assistance from a previous experiment

They also agree with data collected for a "No assistance" condition of a previous study examining the effects of differing damping types (Figure 8). This indicates that the current range of times in the current experiments is comparable with conditions with no force-feedback assistance.

5. Cursor trace analysis

Figure 9 shows the cursor traces for a highly impaired user (PI7) under conditions of no force-feedback haptic assistance for 16 trials in one block. These traces illustrates the typical inaccuracy of the ballistic phase of the movement for this user combined with the effects of overshoot and poor correction after deviation and overshoot has taken place.

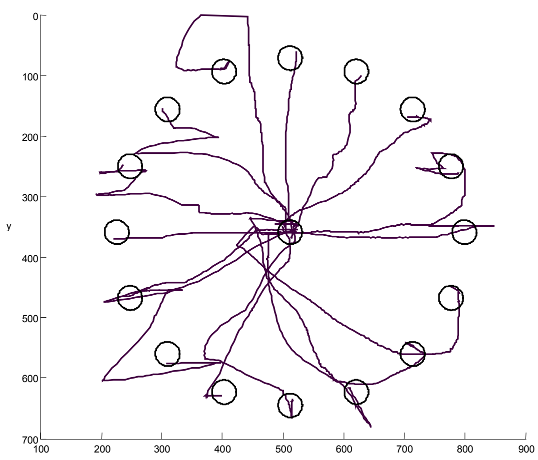

Figure 9. Cursor traces for PI7 with no force-feedback assistance.

5.1 Experiment 1: Cursor trace analysis

It may be that the increased attraction force and range counteracts the disruptive effect of inappropriate cursor capture. Alternatively, attraction to an alternative target may “reset” the navigation, leaving a shorter route that lies within the attractive regions of both targets. One further possibility is that increased force is required of the impaired users to overcome the attractive force of inappropriate targets and that increases the overall force levels for the task with an accompanying increase in speed and reduction of times.

Figure 10 shows cursor traces from user PI7. This user normally displays erratic, inaccurate traces with poor localisation on target, as in Figure 9. However, under the influence of the large overlapping attractive basins, evidence of both improved ballistic movements to target and jumping from adjacent targets to the desired target are present. This suggest that the competing attractive basins may have acted to trap the cursor in the vicinity of the target, facilitating a further move to the target and a faster overall selection time.

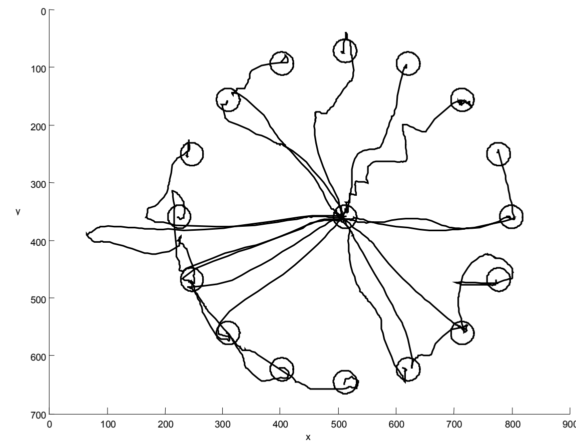

Figure 10. Cursor traces over 16 trials for PI7 with 400% overlapping ellipse size.

5.2 Experiment 2: Cursor trace analysis

The cursor movements under the influence of an unlimited force tunnel with a 20 pixel channel show evidence of increased accuracy of ballistic path. However, there is also evidence of both overshoot, that is constrained to lie within the central channel region, and also of movement outside of the central channel against the mouse force effect. This indicates that the Haptic tunnels used in the experiment are effective at reducing deviations away from the desired path but may only minimally affect any tendency to overshoot by modifying it to lie in the axis of the central channel (Figure 11).

For PI3, PI7, and HA2, task performance with haptic tunnels to targets was significantly improved over the “No Assistance” condition. These users also have the most difficulty moving the cursor in a smooth path (Figure 9). This suggests that part of the improvement is a direct result of smoothing the cursor paths, as suggested in the cursor movement analysis.

For the other users, haptic tunnels did not provide any significant improvements. Users PI2 and PI6 tend to generate smooth cursor paths and both tend to move directly toward the target. It is therefore unsurprising that their times to select the target were unaffected by haptic feedback.

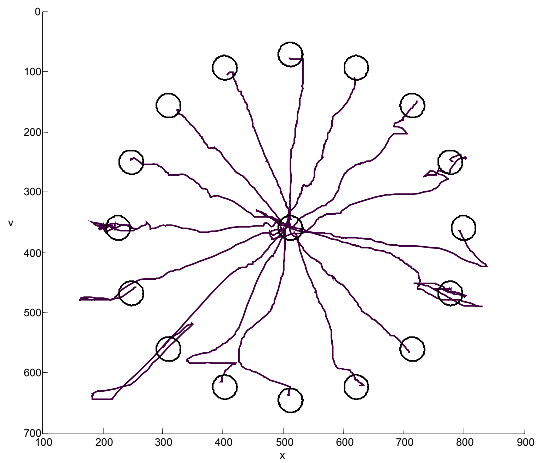

Figure 11. Cursor traces for PI7 with Haptic tunnel with unlimited extent and a 20 pixel central channel.

6. General Discussion and Conclusions

Experiment 1 provides evidence that suggests that the presence of adjacent attractive basins are not disruptive of navigation to target. In particular, there was no increase in average times for the 400% basin size with overlap between basins over the other basin sizes.

Experiment 2 suggests that haptic force channels may only improve times for those with high degrees of impairment. In particular, users with poor navigational ability due to tremor, spasm, weakness and poor control could potentially benefit from forces that prevented movement away from the optimal direction. The level of improvement found ranges between 9%-27% for the three users (PI3, PI7, HA2) for whom it was effective over the various tunnel types. A possible explanation for the low levels of improvement is that difficulties in performing "point and click" tasks often lie primarily in "clicking" rather than in navigating to the target. For example spasm during the button click action can lead to positional disruption of cursor position. As haptic tunnels are principally intended to assist the navigation portion of the task, large reductions in times to target may not result.

The cursor analysis for one individual over a range of conditions illustrated the way in which attractive basins may improve targeting performance for highly motion-impaired users, even under conditions of overlap of basins, and showed how haptic channels are also effective at smoothing cursor paths for the same individual

7. Further work

Continuation of the experimental series will examine the effects of adjacent attractive regions and channels for different tasks in a realistic GUI environment and the role of time-varying adaptation of forces during movement. In particular, the effect of intermediate targets between start and selection target in a variety of geometric configurations on the time to target and cursor traces will be examined , as will the effect if increasing and decreasing the attractive force with proximity to the selection target and adjacent targets

8. Acknowledgements

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