Investigating the use of force feedback for motion-impaired users

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Abstract: For users with motion impairments, the standard keyboard and mouse arrangement for computer access often presents problems. Other approaches have to be adopted to overcome this. There is evidence to suggest that increasing the degrees-of-freedom, and hence bandwidth, of human-computer interaction (HCI), can improve interaction rates if implemented carefully. Haptic feedback is not really exploited in the existing HCI paradigm, so offers a potential method for broadening the interaction bandwidth by complementing the existing interaction structure. This paper describes a series of experiments to assess the effectiveness of using haptic feedback to enhance the interaction. The experiments focused on the use of force feedback technology to assist in point-and-click activities. The results showed that, if implemented appropriately, force feedback offers a significant benefit to motion-impaired users and that the benefit obtained was increased with increasing severity of impairment.

INTRODUCTION

Users with a number of different physical impairment conditions have the same desire to use computers as able-bodied people [Busby97], but cannot cope with most current computer access systems [Edwards95]. Such conditions include athetoid, ataxic and spastic Cerebral Palsy, Muscular Dystrophy and spinal injuries or disorder. Frequent symptoms include tremor, spasm, poor co-ordination, restricted movement, and reduced muscle strength. Similar symptoms are also seen amongst the elderly able-bodied population from conditions such as Parkinson's Disease, strokes and arthritis [Kirkwood99]. Any computer input system intended for use by people with varying physical capabilities and designed around one method of input is unlikely to be flexible enough to cope with the diverse needs and demands of the users satisfactorily. This is not to say that it might not suffice, but for extended computer usage something more flexible and with a broader bandwidth may be required.

This idea is supported by evidence that suggests increasing the degrees-of-freedom of input devices, such as incorporating finger flexion, can improve interaction rates [Zhai96]. Extending this principle to include more degrees-of-freedom through multiple input channels, implies that this should also yield improved information transfer rates. However, increased degrees-of-freedom in the interaction can actually increase cognitive workload if not structured carefully [Keates99]. To maximise the usefulness of the additional interaction modes, it is necessary to for those modes to complement and support the existing ones.

The existing keyboard/mouse/monitor paradigm relies principally on visual feedback, often supported by sound. The use of haptic feedback is restricted to the physical interaction with the specific input device, such as feeling the mouse or touch-typing, but is under-utilised. In the current graphical user interface (GUI) paradigm, icons and windows are directly manipulated but there is no resulting touch (tactile) or feel (kinaesthesic) feedback to the manipulating limbs. This suggests a new potential interaction mode to complement the existing ones.

Motion-impaired users often exhibit decreased motor control and muscle strength, but not necessarily a decreased sensitivity of touch. Consequently, if haptic feedback can be successfully incorporated into the interaction paradigm, then these users may benefit from the enhanced feedback from both touch (tactual) and feel (kinaesthesic). There are two ways in which the use of haptic feedback may enhance the usability of interfaces for the motion-impaired. First, it is possible to use force-feedback to present constant and time-varying forces to the user. These forces have the capability of boosting or aiding user input, in the case of muscle weakness or poor co-ordination, and damping or restraining user inputs, in the case of muscle spasm or tremor. Second, it is also possible to enrich the standard user interface with haptic textures, bumps and edges in order to signal the location of windows, buttons and regions as the mouse passes over them. This is predominantly a touch directed channel, however it may also be implemented on a force feedback device.

Force feedback technology

The sensitivity of motion-impaired users to haptic feedback has been demonstrated using a Phantom [SensAble00]**.** However, this is an expensive research tool that is unlikely to be used routinely as a general-purpose interaction device.

Force feedback has more recently been used to haptically enhance action games using special joysticks. Its implementation is based on the I-Force protocol for haptic feedback [Immersion00]. This protocol describes a library of haptic sensations usable for games such as explosions, inertia and friction, blows and shudders. This technology can also be applied for general user interface purposes. The first non-joystick device on the market to use this protocol is the Logitech force-feedback mouse used in this research. This device is capable of generating both tactual and force-feedback haptic interactions with the user as a result of its very wide range of movement generation capabilities. Studies have shown that this device can improve interaction for able-bodied users in cursor control tasks [Dennerlain00].

INVESTIGATING FORCE FEEDBACK FOR MOTION-IMPAIRED USERS

Two sets of experiments were designed as pilot studies to examine the effectiveness of using force feedback for motion-impaired users. The users were all residents of the Papworth Trust (Cambridge, UK), a charitable organisation dedicated to the care of the motion-impaired, and are detailed in Table 1. In both experiments the ability of the force feedback device to assist both motion-impaired and able-bodied users in a typical GUI point-and-click task was investigated.

User	Description
PV1	Athetoid Cerebral Palsy, spasm, wheelchair user
PV2	Friedrich's Ataxia constant tremor, wheelchair user
PV3	Athetoid Cerebral Palsy, ambulant
PV4	Athetoid Cerebral Palsy, deaf, non-speaking, ambulant
PV5	Athetoid Cerebral Palsy, wheelchair user
PV6	Advanced Kalman-Lamming's Syndrome, ambulant

Table 1. Motion-impaired users from the Papworth Trust.

The users were presented with simple GUI pointing tasks on a standard PC and the times to complete the task with and without force feedback assistance for differing levels of difficulty were recorded. The error rates from missed clicks were also recorded. The aim of the first experiment was to determine whether force feedback offered significant benefit to motion-impaired users. The second experiment focused on evaluating the effectiveness of force feedback for tasks of varying difficulty.

Point-and-click activities were chosen because these are known to present major difficulties to users with a wide range of motion impairments including spasms, tremor and poor co-ordination [Keates98].

Investigating the effectiveness of force feedback

The first experiment involved the users being presented with 16 target circles arranged equidistantly around a central circle (home) on the screen. The aim was for the users to click on each target circle in a random order determined by the software. The target circles became red to indicate the active target and after successfully clicking on the active target, the users had to move back to the home circle before the next target was activated. Four of the motion-impaired users described in Table 1 participated in this trial, PV2, 3, 4, and 6. The experiment was performed with the types of assistance to support the user detailed in Table 2.

Assistance type	Description
None	No additional feedback offered, i.e. normal mouse operation
Pointer trails	Cursor trails from the MS Windows accessibility options
Colour	The target changes colour once the cursor is over it
Gravity well	A force feedback ‘gravity well’ effect added to the target
Vibration	The mouse vibrates once positioned over the target
All	All of the above assistance was combined

Table 2. The types of assistance provided to the users.

The gravity well effect for the force feedback is best described by imagining that there is a second, larger circle around the target. That circle corresponds to the extent of the gravity field. Entering that outer circle causes the cursor to become subject to the gravity and it is attracted by a spring force towards the centre. The average times obtained across all the users are shown in Figure 1.

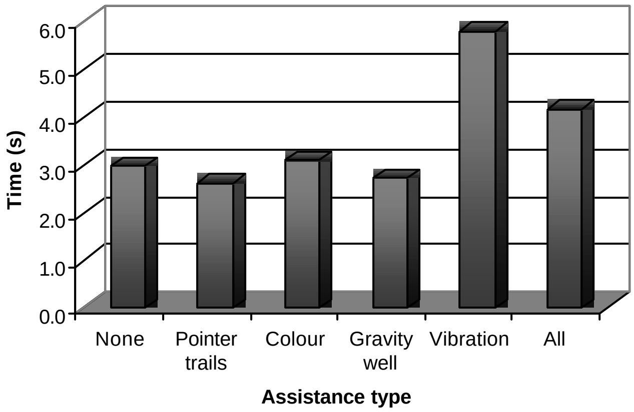


Figure 1. The average time per target, including return home, for the different types of user assistance.

It can be seen from Figure 1 that the use of a gravity well around a target appears to improve the time taken to complete the task by approximately 10-20%.. The most dramatic improvements were seen for the more severely impaired users. For example, Figure 2 shows comparative cursor traces of user PV2 aiming for the target circle without and with force feedback assistance respectively.

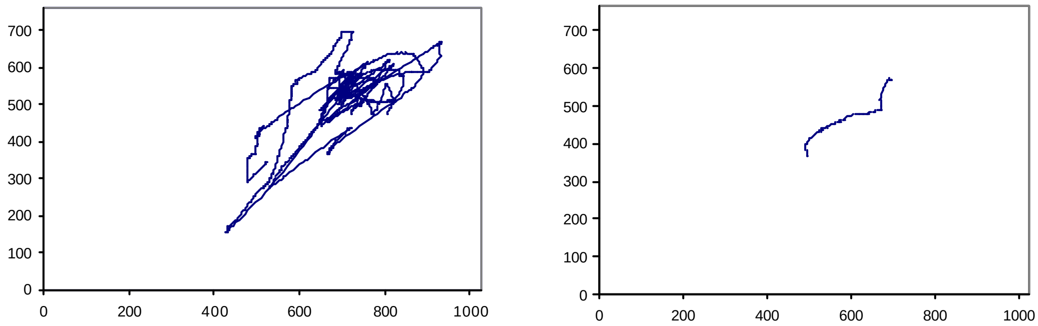


Figure 2. Cursor trace for user PV2 aiming for a 20 pixel target in the top left of the screen: unassisted (left) and with force feedback (right).

The addition of vibration, however, was a retrograde step, almost doubling the time to perform the task. All of the users expressed displeasure at the vibrating sensation when performing this task. The presence of vibration in the ‘All’ assistance type also adversely affected those results. These results mirror those obtained using the Phantom with able-bodied users [Oakley00]. The research effort was therefore concentrated on the gravity well implementation.

Verifying the effectiveness of force feedback

Having established that force feedback, in the form of gravity, appears to enhance and improve the human-computer interaction for motion-impaired users, a second experiment was conducted to verify the significance of the improvement. In the second set of trials, users were presented with Immersion’s Connect-the-dots sample computer application. The program recorded the time taken to complete a sequence of point-and-click tasks, where the targets were distributed in a fixed, irregular pattern across the screen. Each target consisted of two concentric circles. The green coloured inner circle was the actual target to be activated by clicking on it. The blue outer circle indicated the extent of the force feedback locus of attraction, or gravity well, around the target. Positioning the cursor within the blue circle resulted in a spring force towards the green target circle. This task was repeated both with and without the force feedback active. Four motion-impaired users, PV1 through 4, from those described in Table 1 participated in this experiment.

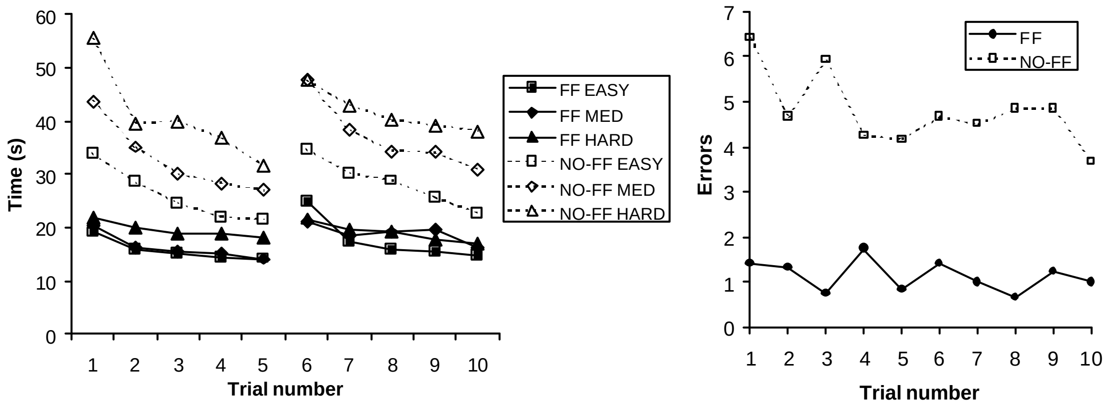
A map of North America was drawn on the screen and the 10 target locations were distributed as fixed city locations on this map. The targets consisted of two concentric circles where the outer circle was of constant diameter and filled with the colour blue. The inner circles radii differed in the difficulty conditions, with the hardest condition having the smallest diameter circle. The inner circles were coloured green. After the start signal was displayed, the user was required to move to, and click on, the inner circle of the target circle whose outer circle area was flashing. Successfully clicking on the centre circle immediately initiated flashing of the next target in the sequence. On completion of the required sequence of targets, the timer was stopped and the number of clicks outside of the centre target circle (misses) displayed. The elapsed time, and start and stop signals were displayed at the top of the screen.

During the force-feedback assisted trials the mouse was strongly attracted to the centre of the target once the outer circle was reached. During the unassisted mouse trials the interface behaved as a normal point-and-click mouse. The program forced a complete training set on the identical stimuli before each force-feedback trial. The users performed the task using the easy, medium and hard settings.

Results

Typical performances were exemplified by two users. User PV2 was unable to perform the task in the unassisted mode taking as long as 364 seconds in one trial to complete half the targets on the easy setting. However this user was able to perform five trials using the force-feedback assistance, showing a substantial learning effect for the task over trials. A consistent number of 2 missed clicks for each set of 10 targets was recorded. This pattern was repeated for the two harder sets of trials although the average time to complete each set increased. User PV5 was able to perform the unassisted interface task, showing an average completion time of around 20 seconds. However, scores were substantially improved during the force-feedback assisted trials, at around half that time on average. This effect occurred for the two harder sets of trials.

Figures 3 and 4 show the times and missed clicks averaged across all the motion-impaired users by trials. It can be seen that there was a considerable improvement in both time to complete trials and error rates with the force-feedback.



Figures 3 (left) **and 4** (right)**.** The times to complete the task and the number of errors (missed clicks) averaged across the motion-impaired users.

Figure 3 shows that the times obtained with force feedback assistance were consistently faster than those without. The step increase in times between trials 5 and 6 arose because the trials were conducted over a period of 2 days, one week apart, and this corresponds to the week-long break in the trials. There is evidence of learning occurring within the two batches of 5 trials, but the step increase implies that there is a potential for unlearning as well without regular exposure. Figure 4 shows that the average number of errors is consistently lower using force feedback than without.

CONCLUSIONS

A strong positive effect of using force-feedback to enhance interaction was observed for motion-impaired users. Using gravity wells around targets was shown to be an effective way of making point-and-click activities easier for motion-impaired users. In particular, the times to complete the trials for the connect-the-dots task were reduced by 30–50% of times for unassisted interaction modes. The improvement that occurred was so marked that motion-impaired users were, in some cases, able to equal and exceed the performance level of able-bodied users performing the same task, most noticeably in the higher difficulty settings.

Of particular encouragement was that the force feedback appeared to be of most benefit to the more severely impaired users, especially those with difficulty performing homing actions. Figure 3 clearly illustrates this effect for user PV2, one of the most severely impaired users participating in the trials. The availability of comparatively cheap force feedback devices, such as the Logitech mouse, and robust programmer development kits for adding force feedback effects to software means that this has the potential to become extremely important technology for enabling universal access to computers.

However, whilst force feedback can be very effective in improving the interaction, it needs to be applied in a manner that is truly supportive and complementary to the existing input. The poor results of the vibration feedback from the first experiment show that inappropriate use of the technology can actually have a negative impact on the interaction. As ever, it is vital to verify and validate the use of the particular application of force feedback through user trials before incorporating it into an interface.

ACKNOWLEDGEMENTS

The authors would like to thank the staff and users at the Papworth Trust for their participation in the user trials. This research is funded by the Engineering and Physical Sciences Research Council.

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