The Human Factors of Touch Input Devices

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The popularity of touch input devices for use in a wide variety of information, telecommunication, and other system applications warrants a review of the role of human factors in the design and use of these devices. This report reviews the existing research on user interaction with touch input devices, specifically touch screens and touch pads. The limitations and capabilities of the devices for supporting a variety of tasks are examined as are comparisons between these devices and more conventional input devices such as keyboards. Attempts to improve the user interaction with these devices are also reviewed. Conclusions and recommendations regarding the use and design of the devices are provided.

Introduction

The use of human touch for controlling objects in our environment is a natural, almost automatic, behavior. It is therefore not surprising that there is a strong propensity to use human touch in operating computer systems and other information and telecommunication systems such as Automatic Teller Machines (ATMs) and public information kiosks. Applications of touch systems are also found where space limitations preclude the use of more conventional input devices such as keyboards. The combined ease of use and efficient use of space led to early applications of touch screen in aircraft cockpits, air traffic control centers, and plant control rooms (Pickering, 1986).

The touch input devices which are of concern in this report fall into two major categories: touch-sensitive input device which overlay display screens (i.e., touch screens) and touch input devices which are separate from the display screen (touch pads). The latter devices are of additional interest because they require some intervention or mediation from the system in order to translate user inputs into display screen actions.

The purpose of this report is to assess the state of touch screen and touch pad technologies in supporting human-system interaction. Of particular interest is how these two types of input device compare to other input devices such as the computer mouse and keyboard. Of additional interest are studies evaluating advances in the design of touchscreen and touch pads that might justify extending their use in human-computer interaction.

Touch Screens

As noted above, some of the earliest applications of touch screens exploited their high degree of integration with display devices. Unlike conventional keyboards, touch screens can be fully integrated with the displays they control. Moreover, because the touch screen is transparent, the controls displayed on the underlying screen can be changed easily. While a review of the early history of touch screen devices is beyond the scope of this report (see the reviews of Pfauth and Priest, 1981; Pickering, 1986), suffice it to note that for the past 30 years the touch screen has found its way into virtually every application of human-system control which could exploit its unique characteristics. More recent applications of touch screen devices have been found in ATMs, information kiosks, personal computers, medical instruments and even kitchen appliances. The ubiquity of touch screens and the likelihood that applications for them will grow rapidly with the spread of information and communication technology warrants an understanding of their underlying technology and how their design might be improved.

Touch Screen Technology

There are three general classes of touch screen technology: One class requires contact with a conductive object, such as a finger, to be activated; a second class of touch screen requires that pressure be applied to its surface; and a third class requires only that an object (any object) come into proximity with the display screen surface. The first of these categories are capacitive touch screens, the second class are cross-point matrix or resistive membrane, and the third class include infra-red and acoustic surface wave touch screens. All of these technologies have as their goal the rapid location (X-Y coordinates) of the surface area being touched.

The infra-red and acoustic wave were among the earliest developments in touch screen technologies. Infra-red (IR) touch screens incorporate emitter-detector pairs along the edges of the display screen. The beams are situated of sufficient height to clear the display surface. When an object, such as a finger, is pressed against the screen it breaks an IR beam and the coordinates are passed to the touch screen device processor. As the beams are invisible to the user, a major advantage of the IR touch screen is that it does not interfere with display image clarity. A major disadvantage, however, is the limited touch resolution resulting from the physical space required of the IR emitter-detector pairs. IR touch screens are also subject to interference from display surface contamination and from sunlight and artificial light interference. User interaction with the touch screens can also be compromised by inadvertent contact with unintended areas of the touch screen as the pointing device is removed from the display surface.

Acoustic surface wave touch screens typically use a glass overlaying the display screen which is used to propagate acoustic waves across the surface of the display. Like the IR touch screen, objects coming into contact with the display surface disturb the acoustic waves, sending an echo back to receivers in the display housing. The coordinates of the disturbed area are sent to the device driver which calculates the location of the touch. As with IR technology, screen surface contamination can affect acoustic wave touch screen performance as can any strong acoustic signal which comes into contact with the display. The main advantage of acoustic technology, like IR touch screens, is its lack of interference with display image quality.

Despite the advantages of these two touch screen types they have not gained widespread use due not only to the problems noted above, but to their high cost of manufacturing and maintenance. Much more common in touch screen applications are the cross-point matrix or resistive membrane touch screens and capacitive devices described below.

Resistive membrane. As with IR and acoustic wave devices, resistive membrane touch screens do not require contact with a conductive object to be activated. Unlike these devices, resistive membrane touch screens require surface pressure to operate. The need for pressure is due to the fact that the resistive membrane overlaid on the display screen contains a sandwich of conductive strips and separators. The separators prevent the contact of the conductive strips until pressure is applied to the membrane surface. The pressure may be applied by a finger or any other object. Because the resistive membrane is applied to the surface of the display screen, some loss of display image quality may occur. Parallax distortion of the underlying image may also occur, though normally this is relatively minor.

Resistive membrane touch screens have the advantage of allowing for higher resolution in the detection of surface touches then either IR or acoustic touch screens. This factor, in addition to lower manufacturing and maintenance costs, has lead to a much wider application of resistive membranes for touch screen input devices. Resistive membranes can also be retrofitted to displays in the field which allows much more flexibility than either IR or acoustic technology.

Capacitive touch screens. As its name implies, capacitive touch screens rely on a conducting object such as a finger or conductive stylus to operate. Like resistive membranes, capacitive touch screens overlay the display surface. Unlike resistive membrane touch screens, capacitive devices do not require surface pressure, only close proximity to the conductive object is required to activate the device. However, if the user's finger is covered by glove material or is contaminated in some way by non-conducting material, the capacitive touch screen cannot be operated. This restricts the technology to those conditions where the user's hands would not normally be covered. For this reason, capacitive touch screens are normally not used where gloves might be worn such as in medical environments, military cockpits or outdoor kiosks. In these situations, the resistive membrane is the touch screen technology of choice.

Comparison with other Devices

Apart from the advantage of eliminating the need for separate control input devices, such as keyboards, touch screens support the "natural" human response to touch objects of interest. Unlike keyboards, mice, and other mediated devices, touch screens do not normally require the user to learn a new interaction behavior. Simply pointing at the desired object on the screen is enough. The touch screen input device is therefore most useful for those users who have not developed skills using other input devices and in those situations where learning such skills is not practical or desirable. Touch screens therefore ideal for ATMs and public information kiosks.

With its natural, non-mediated operating characteristics, it is not surprising that touch screens are preferred by users when compared to other input devices. A study by Karat, McDonald, and Anderson (1986) compared the touch screen, keyboard and mouse in menu selection and text editing tasks and found strong user preference for touch screens. But this user preference will rapidly disappear if the user is required to use touch screens in tasks requiring a high degree of accuracy, tasks typically found in graphics editing, for example. In a cursor positioning task, Albert (1982) found touch screens yielded the worst user performance when compared to other input devices.

In a later study comparing finger-based touch screens with keyboard, mouse, and stylus-based touch screen input devices, Mack and Lang (1989) examined their relative effects on user performance in a graphical interface environment. The three sets of tasks addressed the main categories of user interaction with graphical interfaces: selection, as in selection of window components; double-clicking, as is used to open applications; and dragging, as used to scroll windows or drag and drop objects. Five general task categories were evaluated: menu selection, window management, file operations, calendar/calculator operations, text editing and drawing. Since the study showed an interaction between the input device used and the task categories, data have been recalculated from the study and are shown in Figure 1.

As can be seen in Figure 1, finger-based touch screen input devices resulted in the poorest user performance in all but two of the six task categories. In these two areas (text editing and drawing) , user performance with the finger-based touch screen was approximately the same as with the keyboard. In all but text editing, the finger-based touch screen device resulted in poorer performance than the stylus-based touch-screen.

Examining the use of touch screens in more detail, Mack and Lang (1989) found that the problems with finger-based touch screen input devices in graphical user interface environment reflected an essential incompatibility of this input device with a user interface that has evolved with the mouse in mind. Selection problems often arose with the touch screen because the areas to be selected (e.g., window title bar or window borders) were generally too small to support finger selection. Double-clicking problems occurred because users could not click fast enough in succession to register the action as a double-click. Users also had difficulty clicking (tapping) in the same place successively, the finger often drifting off target. Dragging, a common action in graphical user interfaces, proved difficult due to inadvertent release of the drag when the finger lifted off the screen. As will be seen later, the near-vertical display orientation used in this study played a role in these types of errors. Not surprisingly, users strongly preferred were the mouse and stylus-based touch screen over either the keyboard or finger-based touch screen in this study.

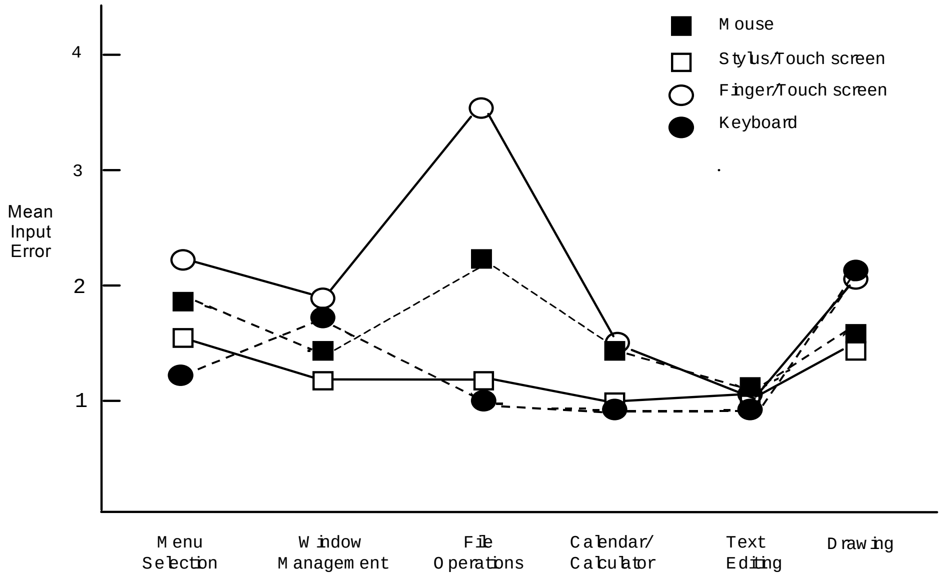

Figure 1. Input error as a function of input device type for six graphical user interface tasks. Data adapted from Mack and Lang, 1989.

In other types of tasks, the lack of any significant tactile feedback has an effect on user performance with finger-based touch screens. Sears (1991) compared touch screen QWERTY keyboards with conventional keyboards in a series of typing tasks. Even with an optimal declination angle of 30 deg above horizontal, the touch screen could only produce typing speeds about half those achieved with conventional keyboards.

Improving Touch Screen Interaction

Clearly, if user performance with touch screens could be improved, much wider application of this input device would undoubtedly follow. In a number of investigations, characteristics of touch screen interface designs have been investigated to determine whether design changes could improve user interaction.

Mounting angle. While technically not apart of touch screen technology, per se, mounting angle of the display on which the touch screen is overlaid will affect user performance. In the display vertical orientation is too severe, users will have difficulty maintaining finger contact with the display. Beringer and Peterson (1985) examined the effects of mounting angles of 90, 75, 60, and 45 deg above horizontal in a target identification task. The largest reduction in user errors occurred when the display angle was reduced from 90 to 75 deg. Smaller gains in error reduction were found when the angle was further reduced from 75 to 45 deg. In the Sears (1991) study of text editing noted above, the 75 deg mounting angle resulted in the poorest performance while angles of 30 or 45 deg above horizontal resulted in the best performance. Users also preferred these lower mounting angles, particularly 30 deg. Additional workstation modifications can also affect user performance with touch screens. Errors and user fatigue in the use of touch screens have been reduced by providing support for the forearm during sustained operations (Ahlstrom, Lenman, and Marmolin, 1992).

Touch biases. Errors in user selection of touch areas are not normally distributed about the target area, but are often biased in a specific directions. In the Beringer and Peterson (1985) study, touch errors tended to cluster below the intended target area. This low bias increases with increases in the declination angle of the display. Sears (1991) also found low bias in errors as well as a bias toward the left of the intended target. Visual parallax with increasing display declination probably accounts for the low bias in errors. However, the left bias in errors found by Sears could have been due to eye dominance effects in that study.

Touch size and shape. Attempts to improve touch screen interaction have also included alterations in the size of the target area as well as the non-sensitive or "guard region" between touch sensitive areas. In an air traffic control task, Gaertner and Holzhausen (1980) found that errors were minimized with target areas of 22 mm. in diameter. Beaton and Weiman (1984) varied target size and guard regions in a target selection task. The smallest number of errors in that study were found with target sizes measuring 10 mm vertical by 20 mm horizontal, separated by guard regions at least 5 mm vertical and 10 mm horizontal. Sears, 1991) in an analysis of touch errors, found target areas of 26 mm square effective in capturing 99% of all user inputs at a 30 deg display mounting angle.

Investigations of key shape were also conducted in a recent study by Breinholt and Krueger (1996). In a touch screen operation of a chemical analyses instrument target selection task, they found that keys shaped as an equilateral triangle (18 mm per side) gave the best user performance. Poorest performance was found with a rectangular shaped key with a triangle hat. The key measured 15 mm tall and 18 mm wide. Next to poorest performance was achieved with a circular key measuring 18 mm in diameter. Evidently the triangular key shape aids in reducing visual parallax effects. It would be expected, therefore, that such a key design could mitigate parallax effects in the greater declination angles of 30 and 45 deg.

Feedback. One of the most widely accepted design principles for user interactions with systems is that user inputs to the system must be provided with feedback or some confirmation that an input has been registered. While resistive membranes provided some tactile feedback, auditory feedback has been shown to be effective in improving user performance with these device (Pollard and Cooper, 1979; Roe, Muto, and Blake, 1984). In a recent study by Shuck (1995), auditory feedback has been shown to be effective in capacitive touch screens as well. In a typing task, a beep tone of 820 Hz frequency was provided whenever a valid area was touched. When compared to a condition where no auditory feedback was provided, typing speed increased about 9 % with the feedback. Interestingly, auditory feedback was only effective with touch typists in this study. As non-touch typists locate keys visually, it is possible that visual (rather than auditory) feedback may be more effective in applications of touch screens with novice typists.

Keyboard size. The flexibility of touch screen technology compared to conventional keyboards has also led to research in keyboard sizing. A study by Sears, et al (1993) compared four QWERTY touch screen keyboard sizes ranging from 6.8 cm to 24.6 cm wide (measured from the Q to P keys). Novice users typed 10 wpm on the smallest keyboard and 20 wpm on the largest keyboard. After practice, speeds increased to 21 wpm for the smallest and 32 wpm for the largest keyboard.

Key interaction strategies. Alternative interaction strategies for touch screen user interaction have also been investigated. While the basic keying strategy used is to activate a target areas with a land-on of the touch, lift-off designs have also been studied. Patter, Schneiderman, and Weldon (1988) found that activation of the touch key on lift-off of the finger was more accurate in a target selection task than the more conventional land-on design. The lift-off strategy, however, slowed task completion performance significantly. The ability to slew the finger to the desired touch area after landing probably account for both the higher accuracy and slower task performance of the lift-off strategy.

Other design strategies have been used to compensate for touch screen interaction problems in a graphical user interface. Following the study of Mack and Lang (1989) described above, Montaniza and Mack (1991) investigated methods of reducing the problems with touch screens by employing various touch control methods. Problems of double-clicking (double-tapping) found in the earlier study were addressed by making lift-off-after-brief-pause equivalent to a double-click. The design proved effective in minimizing double-click problems. Johnson (1995) also found that user preference and accuracy of window scrolling favors a touch which pushes the background of the window in the direction desired rather than the conventional method of scrolling where the contents of the window moves in the opposite direction of the scrolling action. This study suggests that there may be a number of different ways users can interact with a graphical interface which exploit touch screen interaction behavior.

Clearly, a number of design strategy for keying action can be invoked in touch screens to compensate for problems of accuracy, particularly in graphical user interface interaction. It should be noted, however, that all of these new actions come with the price of a user needing to learn a new behavior. Not having to learn a new user interaction behavior is, however, one of the chief advantages of touch screen technology. The introduction of these design strategies for keying should therefore be restricted to those situations where users are willing and able to learn new skills.

Touch Pads

Touch pads evolved from graphical digitizing tablets which were commonly found in early graphical and computer-aided design workstations. The touch pad or touch-sensitive tablet, as it is sometimes called, is an input device which exists separate from the display screen. While any of the touch screen technologies described earlier can be use, capacitive technology is generally used for touch pads, particularly for those in portable computers. Like the keyboard, mouse, and trackball, but unlike the touch screen, control actions on the touch pad are mediated by processor algorithms which affect the amount and type of display movement from a given control input. The essential mediation for touch pads (absolute positioning) and the factor that dictates touch pad size is the control:display or C:D ratio. This ratio determines the amount of display cursor movement for every unit of touch pad control movement input by the user. For example, for a C:D ratio of 1:8, if a user moves his or her finger 1 in on the pad, the cursor on the display will move 8 in. Though much less common, relative positioning may be used instead of absolute positioning. In relative positioning, no C:D ratio applies as the relationship between finger movement on the pad and cursor movement on the screen is a non-linear function. In relative positioning, the designer may chose to amplify the effects on cursor movement of initial movements of the finger, then rapidly reduce the amplitude effects after a specific distance traveled on the pad. In general, absolute positioning designs result in user performance that is faster and more accurate than relative positioning (Arnaut and Greenstein, 1986; Epps, 1987).

Due to its relative recent arrival in the mainstream of information technology input devices, touch pad user interaction research has been much less than that of touch screens. However, some performance data comparing touch pads to other input devices is available. A study by Albert (1982) found the touch pad to be far superior to the touch screen in speed and accuracy of user performance in a target selection task. In a study of graphics editing task performance conducted by Epps (1987), touch pads compared poorly with trackball and mouse when the task involved fine positioning. In a more recent comparison of user performance on eight separate tasks (ranging from text editing to target selection), Cakir and Cakir (1995) found touch pad performance to be poorer than the mouse for all eight tasks. In addition, the authors measured postural discomfort and fatigue during the five hours users operated the touch pad. Both measures were found to be less than those found in operating a conventional keyboard.

Findings in touch pad research need to be tempered by the reality that little research has been done to evaluate this technology. This is particularly true for fatigue and postural discomfort in prolonged touch pad use. Data on higher precision tasks, such as graphics editing and computer-aided design would also help determine the performance limits for touch pads. The popularity of touch pads as devices replacing the trackball and other input devices is likely to continue. Their lower manufacturing and maintenance costs and lowered weight make them an attractive choice for portable computers and telecommunication devices.

Conclusions and Recommendations

A number of conclusions and recommendations on the design and use of touch input devices can be drawn at this stage for touch screens and, to a lesser extent, for touch pads. Touch screens have a long history in military and civilian use and are found in a wide variety of user environments including aircraft, automobile, medical instruments, ATMs, information kiosks, personal computers, and even home appliances. Touch pads, by contrast, have only recently emerged as a common input device in portable computers, pen-based systems, and personal digital assistants. Both stylus-based and finger-based touch pads are increasing in usage.

Touch Screens

Despite attempts to improve the accuracy of touch screens, this input device is generally restricted to tasks where a high degree of accuracy is not needed. If high accuracy is needed for a touch screen application, it is recommended that a stylus-based touch screen be used. The replacement of the finger with a stylus-based touch screen is also generally recommended for graphical user interfaces unless those interface have been specifically designed for finger-based operations.

If a finger-based touch screen is used, display mounting angles should not exceed 75 deg from horizontal with 30 to 45 deg being the optimal mounting angle. For the 75 deg angle, key sizes should be at least 20 mm wide and a minimum of 10 mm tall with vertical guard regions of at least 5 mm and horizontal guard regions of at least 10 mm. Due to increasing parallax problems for 30 and 45 deg angles, touch screen keys should be at least 26 mm vertical and horizontal when used in displays at this mounting angle. Larger guard regions of 10 mm vertically are also recommended at these mounting angles. If design tradeoffs require reductions in key size or guard regions, it is recommended that key size be sacrificed before guard region size as it is generally preferable for users to recover from a non-input error (i.e., missing the touch area) than an incorrect input. Key shape, particularly the use of the equilateral triangle shape may also be used to compensate for parallax problems at the 30 and 45 deg angles. If this shape is used, key size may be safely reduced to 18 mm from the 26 mm recommended for conventional box or circular key shapes. The use of different key input strategies may be warranted for certain applications where user training in the new interaction behavior can be justified. Lift-off key interaction may be useful where certain user interactions like the drag and drop behavior of a graphical user interface are desired. In general, however, it is preferable to reduce user input errors by increasing key size and guard regions and retaining the more natural land-on key interaction.

Touch Pads

Although less is known about user performance with touch pads, they appear to a viable replacement for other devices, such as the mouse, at least in those tasks not requiring great precision. Routine text editing and most interactions common to graphical user interfaces, such as menu selection, can be accomplished with touch pads at a user performance level comparable to trackball or mouse input devices. However, where fine positioning or high accuracy selections are required, the touch pad has been found wanting.

As noted earlier, the touch pad is seeing increased use as a replacement for more conventional input devices such as the trackball and mouse. This has led to increasing concerns regarding the effect of prolonged touch pad use on user fatigue, postural comfort, and even repetitive stress injury. Thus far, there is no indication that touch pads are a problem in this regard, at least for the non-precision tasks evaluated. However, a definitive answer to problems of user fatigue or even injury require large scale user population studies conducted with a wide variety of tasks and working environments. The needed studies have not yet been conducted.

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