A literature review of User Interface interaction devices

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1. Introduction

As part of the project on Human Interface Research for oscilloscopes, there was a need for an inventory of technology and techniques for user interface. This review discusses (the functioning, applications, advantages and disadvantages of) classic, as well as, some more novel interaction devices. These are not necessarily complete and exhaustive lists of possible interaction devices: the increased concern for human factors has led to hundreds of new devices and variants of old devices. Shneiderman (1992) states that:

> "the lively controversy surrounding these devices is healthy, and empirical studies are now beginning to yield comparitive evaluations as well as insights that lead to further innovations (Brown, 1988; Card et al., 1990; Foley et al.,1990; Greenstein and Arnaut, 1988; Sherr, 1988)."

Thus, this review primarily gives a representative overview of current interaction devices.

According to the classical view, a UI of an application can informally be defined as the part of the application that is in charge of the communication with a user. The communication consists of the information exchange in both directions: from the user to the functional part (user inputs) and from the functional part to the user (the application feedback). This is shown in figure 1 (Blattner & Dannenberg, 1992).

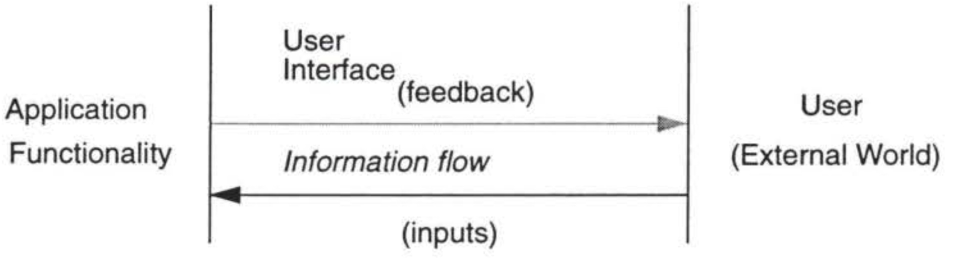

Figure 1: A user interface as an intermediary between a user and the application's functional part.

A newer view defines the UI as the user's total perception of the system in view of achieving the desired goals. It constitutes of all interactions between the users, their goals and tasks, their environments, and the product. This is shown in figure 2.

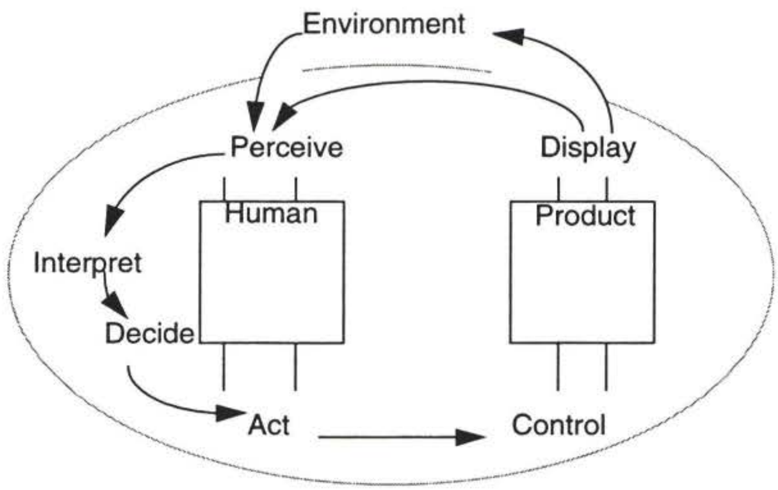

Figure 2: The User Interface: all the attributes of a system which a user can use when interacting with the system (Philips, Interim Report Task Force UI, January '92).

User input and output would benefit from devices supporting the whole range of human communication involving keying, selecting, touching, speaking, looking and gesturing for input, and seeing, hearing and feeling for output. Interaction devices may be discussed in a way that recognizes their functional inter-relations when they are used to perform tasks. Accordingly, the sensory modalities (visual, tactual, auditory) needed for adequate use of these devices, *User-System requirements* (USr), and the *System-User requirements* (SUr) for feedback from the system are taken into account. Feedback is required to support the limitations of the human informationprocessing system. De Vet (1993) described and analyzed feedback along dimensions such as *type*, *content* and *form*.
Feedback types include:

- Status feedback
- Corrective feedback
- Guidance ('feedforward')

For each type of feedback a distinction can be made between the content (i.e. the meaning of) and the form (i.e. the specific representation of) the feedback.

For each group of interaction devices the *types* are distinguished, as well as some *applications* and *implementation issues* for the devices. Besides these requirements the *advantages and disadvantages* of each interaction device can facilitate *initial* decisions as to which devices are appropriate for a given user population, task, environment, or hardware configuration. However, in order to improve the efficiency and effectiveness of a user's performance (i.e. time and effort expended to complete tasks) under given conditions (e.g. the user's job), the selection of an interaction device should involve the following considerations (Greenstein and Arnaut, 1988).

- First, the characteristics of the task, users, working environment, and existing hardware should be determined.

- Next, the characteristics of the candidate input devices should be compared with the re-quirements of the application to narrow the list of candidate devices. Previous research and experience concerning the interaction devices under consideration should be reviewed at this point. User preferences should also be considered.
- Once a tentative selection has been made on the basis of human performance, engineering, and cost considerations, the input device should be tested in (a simulation of) the working environment.

2. Interaction devices

The interaction devices that will be discussed are summarized in the following table:

Table 1: Interaction devices

USr \ SUr	Tactual	Visual	Auditory
Tactual	• Prototype multi-touch 3D touch-sensitive tablet (*V) • Trackball with contextual motor-feedback (*V)	• Controls • Keyboards • Keys • Light Pen • Touch screens • Graphic Tablets • Mice • Trackballs • Joysticks • Pro pointer • Footmouse • Data gloves	
Visual		• Eye tracking device • Displays • Printers (*T)	
Auditory	• Data gloves in combination with voice input (T)	• Eye tracking and voice recognition for input (V)	• Voice recognition systems • Voice synthesis systems

(*V) or (*T) refers to the SUr of this device.
(T) or (V) refers to the USr of this device.

2.1 Output devices

The following output devices are not discussed in detail. The domain of this review includes mostly input devices.

The traditional output devices for interactive computer systems are:

1. Displays (Durrett, 1987; Foley et al., 1990; Helander, 1987; Rupp, 1981; Thorell and Smith, 1990)
USr: Visual
SUr: Visual
1.1. Monochrome displays (e.g. CRT, Plasma panel, LCD)
1.2. Color displays

2. Printers (Shneiderman, 1992)
"Even with good-quality and high-speed displays, people still have a great desire for hardcopy printouts which can be easily copied, mailed, marked and stored."
USr: Visual and Tactual
SUr: Visual and Tactual

3. Voice synthesis
These systems are more recently used as an alternative output device. For information (such as references) about voice synthesis and sound see Mayhew (1992) and Shneiderman (1992).
USr: Auditory
SUr: Auditory

2.2 Controls

USr: Tactual
SUr: Visual

Several basic classes of *controls* are in common use for non-computer devices:

1. On/Off (buttons or function) switches
   1. 1. Pushbuttons
      1. 1. a. Hand pushbuttons
      1. 1. b. Foot pushbuttons
   1.2. Toggle switches
2. Rotary switches (or control dials)
3. Rocker switches
4. Knobs
5. Cranks
6. Thumbwheels
7. Levers
8. Handwheels
9. Pedals

These are the most commonly used controls. For characteristics of these controls and design recommendations, the reader should see Chapanis and Kinkade (1972), Bullinger et al.(1987) and van Wijnen (1989).

Interaction techniques, methods of using input devices that can be employed by the user to specify inputs, are an important component of the UI. The UI interaction techniques initially used in UI's of computer systems are now also added to UI's of non-computer devices such as audio, video equipment and oscilloscopes.

2.3 Keyboards

Keyboards are the primary mode for textual data entry. Most keyboards can be thought of as containing one or more major groups of keys: alpha keys, function keys, cursor keys and numeric keypads.

USr: Tactual
SUr: Visual

2.3.1 Types

Contemporary keyboards
definition: keyboards with only one keypress at a time; dual keypresses are used to produce capitals and special functions.

Chord keyboards
definition: keyboards which provide more rapid data entry by allowing several (or combinations of) keys pressed simultaneously to represent several characters or a word; there are only ten or less keys so that the fingers never travel from one key to another. See also Buxton (1985).

2.3.2 Implementation issues

For *keyboard operating characteristics* see Mayhew (1992).

Layouts of alpha keys

- Qwerty

definition: frequently used letterpairs are put far apart (thereby increasing finger travel distances).

- Dvorak

definition: the distance between the most frequently used keys is smaller than on the Qwerty keyboard.

• ABCDE style
definition: the 26 letters of the alphabet are laid out in alphabetical order from left to right and top to bottom.

2.3.3 Advantages and disadvantages of keyboard layouts

+ With the Dvorak layout the workload distribution between the hands appears to be more evenly balanced thereby reducing finger travel distances by at least one order of magnitude.
- The Qwerty layout has a disadvantage in cases where keyboard size is important for example in portable equipment.

2.4 Keys

USr: Tactual
SUr: Visual

2.4.1 Types

Function keys
definition: (small rectangular array of) keys (on a pad) for special functions or programmed functions. The keys may be named permanently, or they may be named with plastic overlays which can be changed so that the keys can assume different functions at different times. Keys that manipulate state information are best implemented with lights inside them so that the user can tell at a glance the value of the parameter.

Types of function keys:

• "Hard function keys"
definition: function keys which always perform the same functions.

• "Soft function keys"
definition: function keys whose functions vary according to circumstances.

• "User-defined function keys"
definition: soft function keys that the user can program to perform chosen functions.

Implementation issues of function keys

<u>Layouts of function keys</u>
For issues regarding the *layout of function keys* see Mayhew (1992).

Advantages and disadvantages of function keys

+ can reduce keystroke and errors.
- may not be apparent to some users.
- users must remove their fingers from the home position to use the function keys.

Cursor movement keys or arrow keys
definition: up, down, left, right keys; these keys have a typematic (auto-repeat) feature.

Implementation issues of cursor movement keys

<u>Layouts of cursor keys</u>
For a study on various cursor key layouts see Good (1985).

Applications of cursor keys

The cursor keys on most computer keyboards are used for moving the cursor in specified directions through text, menu options, fill-in fields, or other display objects.

Numeric keypad
It is generally recommended that a numeric keypad be provided that is separate from the alpha keys.

Implementation issues of keypads

<u>Keypad layouts</u>
• Telephone layout: starts with 1 in the upper-left corner.
1 2 3
4 5 6
7 8 9
  0

• Calculator layout: starts with 7 in the upper left-corner.
7 8 9
4 5 6
1 2 3
0

Advantages and disadvantages of keypad layouts

+ The available studies (Deininger, 1960; Lutz and Chapanis, 1955) suggest that the telephone layout may yield superior performance, because of the familiarity of most computer users with the telephone layout. And besides this people usually start reading at the top-left.

2.5 Direct pointing devices

Direct pointing devices offer direct control on the screen surface.

USr: Tactual
SUr: Visual

2.5.1 Types

2.5.1.1 Light pen

definition: device that enables users to point to a spot on a screen and to perform a select, position, or other task; they vary in thickness, length, weight, shape and position of buttons.

2.5.1.1.1 Implementation issues

Modes of operation

• Pointing mode: a character or figure may be selected by pointing to a spot on the display and enabling the light pen.

• Tracking mode: the operator aims the light pen at a display cursor and then moves the pen; as long as the cursor remains in the light pen's field of view, a line will be traced to where the pen is moved. The light pen must be moved at a steady rate or the cursor will be lost and tracking will be interrupted.

Target size

The appropriate size and spacing of the display targets depends to some extent upon the field of view of the light pen. A large field of view may make it easier to select a small target, but it also requires that the targets be widely spaced to permit discrimination between adjacent targets. See also Hatamian and Brown (1985) for light pens with an improved resolution capability.

2.5.1.1.2 Advantages and disadvantages of the light pen

+ the output display is used as the input interface; this provides a direct relationship between output and input.
+ allows natural pointing and gestures to be used to input data.
+ doesn't require extra deskspace.
- the operator of the light pen must sit within arm's reach of the display.
- holding the light pen to the screen can be fatiguing.
- Users' hand obscures part of the screen.
- Users must remove their hands from the keyboard.
- Users must reach to pick up/put down the light pen.
- parallax may be a problem, especially when pointing to objects at the sides of the display; a solution might be to make targets at the sides of the screen large enough to minimize the effects of incorrect placement. Operator training may also be useful.

2.5.1.1.3 Applications

- most useful in locating and moving symbols on a display (Parrish, Gates, Munger, Grimma, and Smith, 1982).
- for menu selection (due to its natural pointing gesture).
- it may be used for drawing, but it is not suitable for precise sketching (Scott, 1982).
- it is not capable of tracing from paper copy.

2.5.1.2 Touch screen

definition: device that produces an input signal in response to a touch or movement of the finger on the display.

Types of touch screens

- Conductive, capacitive, and cross-wire devices.

Principle of touch screen operation: an overlay is contacted.

- Acoustic and infrared touch screen.

Principle of touch screen operation: beams projected across the screen are interrupted by the finger

2.5.1.2.1 Implementation issues

Touch key design
For a comparison of 10 touch screen key design see Valk (1985).

Key size and separation between keys
Beaton and Weiman (1984) varied the horizontal and vertical size and separation of touch keys used with a conductive touch screen for a target selection task. Weiman, Beaton, Knox, and Glasser (1985) used an infrared touch screen.

Feedback and acceptance of input
Weiman et al. (1985) studied feedback of both the current cursor location and the correctness of an operators' actions.
Beringer and Peterson (1985) studied the response biases inherent in touch screen use and the effects of feedback and software compensation on these errors.
In a second experiment of Beringer and Peterson two methods of decreasing this response bias were tested: providing feedback to train the operators and incorporating software to compensate for the bias.

Environmental limitations: dirt and static electricity (which attracts dust) can be a problem for some touch screens. Acoustic devices may be activated by dirt or scratches on the glass. Infrared beams can be broken by dirt or smoke. Capacitive touch screens are not appropriate for users who wear gloves.

Ease of use
• touch screens require a natural pointing gesture.
• touch screens require minimal training in the basic concept.
users need to understand that e.g. the display of an infrared device does not need to be touched; if not: inadvertent activation as well as incorrect target selection due to parallax may occur.
• if too much pressure is required to activate the overlay, activation may take longer and lead to user discomfort.
• low resolution touch screens may be frustrating if touch points are not centered over the targets.

2.5.1.2.2 Advantages and disadvantages of touch screen devices

+ the input device is also the output device; there is a direct eye-hand coordination and a direct relationship between the user's input and the displayed output.
+ all valid inputs are displayed on the screen; no memorization of commands is required.
+ individuals can become quite skilled at target selection in a short period of time because of the natural pointing gesture for input (thereby minimizing training and the need for operator selection procedures).
+ relatively low price.
- the user must sit within arm's reach of the display because the output surface is also the input medium; this may constrain both workplace design and operator mobility.
- the user must continually lift a hand to the display and may experience arm fatigue.
- the user's finger or arm may block the screen.
- limited target resolution is possible due to the size of the operator's finger; with devices other than the capacitive touch screen, a stylus may reduce this problem, but the pointing gesture becomes less natural and the user must then pick up a device before touching the screen.
- since the touch screen must be fitted onto a display, there may be a problem with retrofit if the display has already been purchased.

2.5.1.2.3 Touch screen applications

• best used to work with data already displayed on the screen.
• useful in applications where it is time consuming or dangerous to divert attention from the display e.g. air traffic control tasks (Gaertner and Holzhausen, 1980; Stammers and Bird,1980) and tactical display workstations (Davis and Badger, 1982).
• beneficial in other high workload or high stress situations where the possible inputs are limited and well defined, as in plane cockpits for navigation purposes (Beringer, 1979).
• effective when many users are unfamiliar with the system e.g. to provide information in shopping malls, banks, and hotels.

• useful in menu selection tasks.
• selection or entry of single characters (or small items), however, is slow and may be beyond the resolution capabilities of the device.
• inefficient for inputting new graphic information or freehand drawing (Pfauth and Priest, 1981).

Comparison of touch screen technologies

Resolution
• Highest touch resolution: Conductive screens (1000 x 1000 - 4000 x 4000 discrete touch points).
• Capacitive screens (256 x 256 touch resolution).
• Acoustic touch screens (touch resolution greater than infrared screens but lower than capacitive screens).
• Infrared screens: 25 x 40 touch points due to limitations on the number of light beams that can be placed around the screen (Logan, 1985).
The greater the number of touchpoints, the easier it is to map them to targets on the display.

Parallax: occurs when the touch surface or detectors are separated from the targets. The parallax problem is increased when infrared touch screens are used with curved CRT displays.

Durability: primarily a problem in dirty environments and in cases of continual use. Capacitive and infrared screens tend to be most resistant to damage while conductive and acoustic touch screens may be scratched.

Optical clarity: when an individual uses a touch screen for extended periods of time; a decrease in display quality can lead to operator strain and fatigue. Infrared touch screens are the best in preserving optical clarity because there is no overlay to obscure the display.
Acoustic touch screens may not reduce display clarity (because they have a glass overlay) as much as conductive, capacitive, and cross wire devices which tend to reduce the amount of light transmitted from the display.

Empirical results
Schulze and Snyder (1983):
• Highest display resolution: infrared device (no overlay).
• Least display noise in terms of display luminance variation and CRT raster modulation: Capacitive device.
• Best performance (on the basis of errors and total time to complete three tasks): infrared and cross-wire devices.

Baggen (1987):
• Infrared touch screens provided the best performance (modeled from image quality and touch characteristics data).

• For tasks involving both reading and touching the display image quality is a critical determinant of performance.
• For accurate input, touch characteristics such as parallax and glare are critical determinants of performance. See also Brown (1988) for more about this topic.

2.6 Indirect pointing devices

Indirect pointing devices offer indirect control away from the screen surface; they eliminate the hand-fatigue and hand-obscuring-the-screen problems but must overcome the problem of indirection.

USr: Tactual
SUr: Visual

2.6.1 Types

2.6.1.1 Graphic tablets

definition: a flat panel placed on a table in front of or near the display; the tablet surface represents the display, and movement of a finger or a stylus on the tablet provides cursor location information.

2.6.1.1.1 Types of graphic tablets

• *Matrix-encoded tablets*
definition: Graphic tablets which have a special stylus or pucks that detects electrical or magnetic signals produced by a grid of conductors in the tablet.

Voltage-gradient tablets also have a conductive sheet as the surface of the tablet. Since the stylus must contact the tablet surface, paper cannot be placed on this tablet for such operations as tracing or digitizing.

• *Acoustic tablets*
definition: Graphic tablets which have a stylus that generates a spark at its tip; the sound is detected by microphones mounted on adjacent sides of the tablet.

Electroacoustic tablets
definition: Graphic tablets which generates electric pulses on the tablet that are detected by a stylus; electroacoustic tablets are quieter than acoustic tablets and are less sensitive to noise in the environment (Newman and Sproull, 1979).

• *Touch-sensitive tablets*
definition: Graphic tablets which work without a special stylus; a disadvantage of these tablets is that inadvertent touches can activate them; the tablets may be designed to minimize this possibility.

Touch-sensitive acoustic tablet
definition: high frequency waves are transmitted across a glass surface; these waves are reflected back to the tablet edge when they are interrupted by a finger.

Conductive touch-sensitive tablets: several conductive layers are used at the tablet surface; when the layers are pressed together, an electrical potential is generated (Ritchie and Turner, 1975).

For a more detailed discussion of tablet technologies, see Mims (1984) and Ritchie et al. (1975).

Light buttons: A common technique in systems using tablets is to display an array of command names in some portion of the screen. Pointing at these names is then interpreted as a signal to carry out the associated command. Because of the similarity of this technique to the use of a function box or button box, these command names are known as light buttons.

2.6.1.1.2 Implementation issues

Method of cursor control
• Absolute mode: when an individual places a finger on the tablet, the display cursor can be programmed to move from its current position and appear at a position that corresponds to the location of the finger on the tablet. Movement of the finger on the tablet generates new cursor locations that are always referenced to the current coordinates of the finger on the tablet.
• Relative mode: the display cursor is maintained at its current position when the finger is initially placed on the tablet. Movement of the finger produces a corresponding cursor movement that is always relative to the initial cursor location. Arnaut and Greenstein (1986) found that an absolute mode resulted in faster target acquisition rates than did relative mode, as did Epps, Snyder, and Muto (1986). Ellingstad, Parng, Gehlen, Swieringa, and Auflick (1985) reported that there was less error on a compensatory tracking task with the absolute mode. However, when circumstances dictate that the tablet be small in comparison to the display, absolute mode requires that small movements on the tablet be made to move the cursor a large amount in the display. Relative mode might be preferred since the amount of movement of the display cursor resulting from a movement on the tablet is not dictated by the tablet size.

Display/control relationship
The amount of movement of the display cursor in response to a movement on the tablet is referred to as display/control gain (for a general discussion of control-display relationships, see Chapanis and Kinkade, 1972).
Tablet gain can interact with the cursor control method. When a tablet is used in absolute mode, the tablet size is dictated by the gain, because the location of the finger on the tablet is directly translated into a corresponding position on the dis-

play. With relative mode the finger can be anywhere on the tablet since the display cursor is driven by finger movement, not finger location. thus the size of the tablet is independent of the tablet gain. However, if the size of a tablet used with relative mode and a given gain is such that a movement across the entire tablet surface does not result in a comparable move of the cursor across the display, then the user will have to make several sweeping movements with his or her fingers to move the cursor across an appreciable part of the display. This situation arises when a small tablet is used with a low gain.

It is possible to program a tablet in relative mode to include a gain component that is proportional to finger velocity in addition to the position gain just discussed. For a comparison of a pure position-gain system with a position- and velocity-gain touch tablet (referred to as a lead-lag compensation system) see Becker and Greenstein (1986).

While gain is an important feature of some interfaces, it should be noted that in cases where more than the overall display size and the amount of movement allowed on the input device are changed, gain may be an inadequate specification for performance. Arnaut and Greenstein (1987) report that when target size is also changed, gain may not account sufficiently for performance since it only considers two of the three important display/control components.

Tablet configuration

The tablet size is free to vary from one that fits in a keyboard to an entire digitizing table.The low profile of the tablet in comparison to a joystick or trackball makes inadvertent activation less likely. An additional advantage of the tablets's flat surface is that it may be configured in many ways. A template may be placed over the tablet to correspond with positions on the display in a menu selection task. Alternatively an overlay may indicate operations that are not directly referenced to the display.

Brown, Buxton, and Murtagh (1985) suggest that the tablet surface may be divided into separate region analogous to display windows, with each region configured as a different *virtual input device*. This capability can be useful in system prototyping to aid in making hardware decisions for the system.

Feedback and confirmation

Swezey and Davis (1983) suggest that, as a consequence of the indirect nature of the graphic tablet, it is important to include a feedback and/or confirmation mechanism. This can be done with an audible click or tone and/or a visual indication to signal that an entry has been recognized. Visual and auditory feedback are especially helpful with graphic tablets since no useful tactile feedback occurs when pressing the tablet. A problem related to confirmation is "fall-out" or "jitter" (Buxton, Hill, and Rowley, 1985; Whitfield, Ball, and, Bird, 1983). As the finger is removed from the tablet, the centroid of the finger pressure shifts, and the display cursor moves in response. There are at least three ways to avoid fall-out:

1. using a stylus to focus the area over which pressure is applied.
2. discarding the last few data samples after lift-off so that the cursor remains in the position it was in just prior to the removal of the finger from the tablet.

3. the user could leave his or her finger on the tablet and press a confirmation button with the other hand.
For a studie on methods of confirming an entry for several tasks, see Ellingstad et al. (1985).

Finger versus stylus control
A touch sensitive tablet can be used with either a finger or a stylus. The advantage of using a finger is that there is no stylus to loose or break. A stylus, however can provide greater resolution since area over which it applies pressure is smaller than that of a finger, and it also allows an operator to make small movements by moving the stylus with the fingers without requiring the entire hand or arm to move. Ellingstad et al. (1985) reported that for cursor positioning, compensatory tracking, and function selection tasks, the use of a stylus resulted in faster and more accurate responses than did the use of a finger.

Input dimensionality
Touch tablets can transmit information in more than two dimensions; for examples see Buxton et al. (1985).

2.6.1.1.3 Advantages and disadvantages of graphic tablets

+ the movement required by a tablet and the display/control relationship are natural to many users.
+ the graphic tablets may improve productivity because the user is not required to translate a command or movement into a series of keypresses (Swezey and Davis, 1983).
+ since the tablet surface is constructed of one piece with no moving parts, tablets are suited for "hostile" environments in which other devices may be damaged (Buxton et al., 1985), and it can be easily cleaned.
+ in comparison with touch screens, Whitfield et al. (1983) identify four advantages of the tablet:
1. the display tablet may be positioned separately according to user preference.
2. the user's hand does not cover any part of the display.
3. there are no parallax problems.
4. drift in the display will not affect the input.
5. the user is not likely to experience fatigue associated with continually lifting a hand to the screen.
- the most difficult problem is providing good feedback to the user when using the graphic tablet. For example buttons and other controls implemented on graphic tablets lack the kinesthetic feel associated with real switches and knobs.
- graphic tablets do not allow direct eye-hand coordination, since they are removed from the display.
- the tablets can take up a great deal of space, although small tablets can be inserted in a keyboard.
- because the tablet operation in relative mode requires the user to slide the finger on the tablet, soreness and fatigue due to friction may be a problem over

extended use periods. It is important to adjust the tablet so that the required does not fatigue the operator.
- fatigue may also occur if users must hold their arms and hands away from the surface to avoid inadvertent tablet activation.

2.6.1.1.4 Applications

• better suited to drafting (Ohlson, 1978; Rouse, 1975), freehand sketching (Ellis and Sibley, 1967; Hornbuckle, 1967), or producing a three-dimensional picture (Sutherland, 1974) than virtually any other input device.
• Parrish et al. (1982) recommend that graphic tablets be used for all drawing purposes.
• appropriate to select an item from an array or menu, especially when a template is used.
• while tablets are increasingly becoming more efficient at recognition of handwritten characters, alphanumeric data entry is typically slow since such data entry is usually performed by selecting characters from a menu.

2.6.1.2 Mice

definition: a small hand-held box with one to three buttons that fits under the palm or fingertips. Cursor movement is generated by the movement of the mouse on a flat surface. To perform such functions as changing menus, drawing lines, or confirming inputs the buttons are pressed.

2.6.1.2.1 Types

• *Mechanical mice*: movement of the mouse is detected mechanically; rotation of the small ball, mounted in the bottom of the mouse, is sensed by potentiometers or optical encoders and used to determine orientation information.

• *Optical mice*: movement of the mouse is detected optically; instead of the rolling ball, optical sensors are used to track the passage of the mouse across a grid of horizontal and vertical lines printed on an accompanying pad.

• *Acoustical mice*: provides, in combination with a three-dimensional sonic (i.e. acoustic) tablet, three-dimensional coordinate information. The values returned are in tablet coordinates. Software converts the tablet coordinates to user or world coordinates.

2.6.1.2.2 Implementation issues

Display/control gain
The gain of the mouse may be changed: movement of the mouse may result in either more, less or the same amount of movement of the cursor on the screen. However, unlike the graphic tablet, the mouse works only in relative mode.

Use of mouse buttons

A comparison by Price and Cordova (1983) suggested that in the case of two equally likely responses, it may be better to associate each response with a single click of a different button than with a different number of clicks of the same button; as a consequence it is desirable to include more than one button on a mouse.

Mouse configuration

Hodes and Akagi (1986) conducted a series of studies to accommodate the way users hold, move and actuate the device. For details concerning the preferred design features of mice see (Hodes and Akagi, 1986).

2.6.1.2.3 Advantages and disadvantages of mice

+ mice can work in small spaces because the mouse can be picked up and repositioned.
+ the operator can usually locate and move the cursor while looking at the display.
+ cordless mice which use infrared beams are available, so that a cord does not interfere with the use of the device.
- the mouse does require some space in addition to that allotted to a keyboard.
- pickup and replace actions are necessary for long motions.
- the mouse may move during confirmation because the confirmation button is on the device and this may lead to difficulty in selecting small targets.
- the mouse can only operate in relative mode and is not able to trace drawings or handprint characters; due to these features its usefulness for graphic applications is limited.
- drawing with a mouse is not as natural as is drawing with a pen or pencil.

2.6.1.2.4 Applications

• the mouse is best suited for pointing and selection tasks.
• it is capable of performing drawing and selection tasks, but the graphic tablet may provide a better interface for such applications.

Comparison of mouse types

• Mechanical mice may produce some noise during movement, and dust from the table surface may become lodged inside the mouse.
• Optical mice make no noise, because they have no moving parts.
• Mechanical mice operate on almost any surface.
• The operation of optical mice is confined to the special pad.
• Resolution of optical mice may be lower than that of mechanical mice.

2.6.1.3 Trackballs

definition: "an upside mouse" which is composed of a fixed housing holding a ball that can be rotated freely in any direction by the fingertips. The display cursor is moved through the rotating motion of the ball: movement of a trackball is detected by optical or shaft encoders; this in turn generates output which is used to determine the movement of the display cursor.

2.6.1.3.1 Implementation issues

The diameter, rotational inertia, and frictional drag forces of the trackball may all be adjusted. Display/control gain must also be specified. Like the mouse, the trackball is solely a relative mode device. A gain component that depends on rotational velocity can be added to the position gain that depends on rotational displacement. Rapid movements of the ball will then result in larger cursor movements per unit of ball rotation than gradual movements. The trackball's gain function may then be adjusted so that both gross movement speed (for which high gain is appropriate) and fine positioning accuracy (which requires lower gain) are possible.

2.6.1.3.2 Advantages and disadvantages of trackballs

+ the trackball can be comfortable to use for extended periods of time because users can rest the forearm, keep the hand at one place, and spin and stop the trackball with the fingers.
+ the trackball provides direct tactile feedback from the ball's rotation and speed.
+ it requires a small fixed amount of space.
+ the trackball can be installed in a keyboard.
+ it can be located and operated without taking the eyes off the display.
+ unlike mice, trackballs cannot be inadvertently run off the edge of the work surface.
- due to the fact that the trackball operates only in relative mode, its usefulness for drawing tasks is limited: it cannot be used to trace drawings or to handprint characters.

2.6.1.3.3 Applications

• best suited for pointing and selection tasks.
• Parrish et al. (1982) suggest that trackballs should be used to draw lines and sketch when requirements for drawing speed and accuracy are not very stringent.
• Parrish et al. suggest that trackballs are excellent for designating and moving symbols on a display.

2.6.1.4 Joysticks

definition: A joystick is a two dimensional control constructed typically as a small strain gauge on which is mounted a rubber knob. Applying force to the joystick in any direction causes the cursor to move in the appropriate direction.

2.6.1.4.1 Types

• *Displacement joysticks*: these joysticks use potentiometers to sense movements of the lever. The lever may be spring-loaded so that it returns to the center when released.

• *Switch-activated or binary joystick*: movement of the lever generates an output signal which is not proportional to the magnitude of the lever displacement. When the spring-loaded lever is released it returns to center and the cursor stops moving.

• *Force or isometric joystick*: has a rigid lever that does not move noticeably in any direction. The cursor moves in proportion to the amount of force applied. When the lever is released the output drops to zero.

2.6.1.4.2 Implementation issues

Display/control gain
The gain of the joystick may be changed. Foley and van Dam (1982) note the importance of incorporating a small dead zone of zero velocity around the center position of a rate-control joystick so that nulling the joystick input is not difficult.

Force-displacement relationship
The force-displacement relationship of a joystick specifies the displacement of a joystick that results from applying a specific force. The various displacement joysticks offer at least some resistance to displacement and in this case there are two common relationships between the force applied to the joystick and its resulting displacement: elastic and viscous resistance. When a joystick has elastic resistance, the application of a constant force to the joystick results in a constant joystick displacement; with vicious resistance this results in a constant rate of joystick movement.

2.6.1.4.3 Advantages and disadvantages of the joystick

+ the joystick acquires only a small amount of desk space, and it can be made to fit into a keyboard.
+ if a palm or hand rest is provided, the joystick may be used for extended periods of time with little fatigue (Ritchie and Turner, 1975).
- the modest size of most joysticks leads to gains too high for accurate positioning in absolute mode; this limits their usefulness for drawing tasks.
- joysticks cannot be used to trace or digitize drawings.

2.6.1.4.4 Applications

• best suited to continuous tracking tasks and pointing tasks that do not require a great deal of precision (Mims, 1984).
• a joystick in absolute mode may be used for line drawing if high accuracy and

speed are not required (Parrish et al., 1982).
• rate-control joysticks are useful for locating and moving symbols and selecting menu items.

2.6.2 Further issues concerning hand-operated interaction devices

There are some principles about using hand-operated devices (such as controls, keys and pointing devices). For instance, Fitt's law states that the time to move your hand to a target item is a function of both the distance and size of the target item. As a consequence, items that are a long way should be bigger if the user is not to spend extra time.

2.7 Voice recognition devices

Voice or speech recognition enables the user to speak to the computer in situations where the user is already overloaded with visual and manual tasks.

USr: Auditory
SUr: auditory

Speech technology has four components: discrete-word recognition, continuous-speech recognition, speech store and forward, and speech generation. A further topic is the use of audio tones, audiolization, and music. These components can be combined in creative ways: from simple systems that merely playback or generate a message, to complex interactions that accept speech commands, generate speech feedback, provide audiolizations of scientific data, and allow annotation and editing of stored speech. The first two components (which form *voice recognition*) are input devices, the remaining (forming *voice synthesis* and *sound*) can be considered as output devices (e.g. for feedback).

2.7.1 Types

• *Discrete-word recognition devices*
definition: these devices recognize individual words spoken by a specific person; they work with 90- to 98-percent reliability for vocabularies of from 50 to150 words.

Speaker-dependent systems
These systems require that the users train the device to their speech characteristics (e.g. pitch, accent) by reciting each word in the recognition vocabulary. The number of speakers supported by the device is related to the storage capacity of the device.

Speaker-independent systems
These systems are able to accept input from any speaker using the recognition

vocabulary; they do not require a training period. These systems are under development (recognition of 10 to 20 words: Helander, Moody & Joost, 1988) and are beginning to be reliable enough for certain commercial applications.

• *Continuous-speech recognition devices*
definition: these systems enable the recognition of natural sentences (that is, connected words) without the need for pause insertion.

Although many research projects have pursued continuous-speech recognition, most observers believe that a commercially successful product will not be forthcoming within the next decade or two. The difficulty revolves around recognizing the boundaries between spoken words. Continuous-speech recognition products are offered by manufacturers such as Verbex, which claims greater than 99.5-percent accuracy with speaker-dependent training with vocabularies of up to 10.000 words, and Speech systems, which claims 95-percent accuracy for speaker-independent systems with 40.000 word vocabularies. See also Peacocke and Graf (1990).

2.7.2 Advantages and disadvantages of voice recognition

+ voice input, by contrast with other input devices, requires neither the hands or eyes to operate, and with a remote, hand-held or head-mounted input microphone, it can be operated at any distance from the system itself.
- voice input is transient; there is *no natural feedback* mechanism allowing users to verify their input, the way there is when typing or pointing on a screen. Adding verification procedures inevitably slows throughput down significantly (Isenberg, Yntena, & Wiesen, 1984).
- voice input in systems operating in public or open office environments can be very *disruptive* to others and suffers from a *lack of privacy and security* as well.
- voice input may actually be more *fatiguing to use* over long periods of time than many hand-operated input devices.
- it might also actually be *slower* than other input devices for many operations (Murray, Van Praag, & Gilfoil, 1983).
- speech is a *single-channel mode*: users cannot speak two or more messages simultaneously, and they cannot listen while speaking.
- the current *error rates* of voice-recognition systems, due to the sensitivity of these systems to noise in the environment and variations in speech within and across speakers, is a disadvantage as compared to other devices.

2.7.3 Applications

• Applications for the physically handicapped have been successful in enabling bedridden, paralyzed, or otherwise disabled people to control wheelchairs, operate equipment, or use personal computers for a variety of tasks.
• Current systems work effectively when the following conditions exist:
    • Speaker's hands are busy

- Mobility is required
- Speaker's eyes are occupied
- Harsh (underwater or battlefield) or cramped (airplane-cockpit) conditions preclude use of a keyboard

• Current systems work effectively only in *controlled environments* with minimal background noise.
• Aircraft-engine inspectors who wear a wireless microphone as they walk around the engine; they can issue orders, read serial numbers, or retrieve previous maintenance records by using a 35-word vocabulary.
• Speech recognition has been tested in military aircraft, medical operating rooms, training laboratories, and office automation. The results reveal problems with recognition rates, even for speaker-dependant systems, when background sounds change, when the user is ill or under stress, and when words in the vocabulary are similar (due to natural variations in human speech, weaknesses in the recognition algorithms, and the phonetic distance or discriminalibility between word templates). Helander, Moody, and Joost (1988) also reviewed current applications from industry and consumer products. See also Halstead-Nussloch (1989) and Hauptmann (1989) for more information about this topic.

2.8 Novel input techniques

2.8.1 Types

2.8.1.1 Pro pointer

definition: The Pro Pointer fits into a space less than 40 cm square (6 inch square), and it can either stand alone or be integrated into a keyboard. The device has a handle approximately the size of a standard key on a keyboard. The handle can also be depressed to provide the functionality of a button switch.

USr: Tactual
SUr: Visual

2.8.1.1.1 Implementation issues

The Pro Pointer uses a light emitting diode and an optical sensor to generate X and Y coordinates when the small handle is moved (Moran, 1987).

2.8.1.2 Multi-touch three dimensional touch-sensitive tablet

definition: apart from *touch sensing* of touch-sensitive tablets, this tablet has the following additional features:
• it can sense the degree of contact in a continuous manner.
• it can sense the amount and location of a number of simultaneous points of contact; so in addition to being able to provide position coordinates, the tablet also gives a measure of degree of contact, independently for each point of contact (Lee, SK., Buxton, W., & Smith, K.C., 1985).

USr: Tactual
SUr: Visual and Tactual

2.8.1.2.1 Implementation issues

In order to enable multi-touch sensing, the tablet is divided into a grid of discrete points. The points are scanned using a recursive area subdivision algorithm. Additional technical details can be found in Lee (1984).

2.8.1.2.2 Advantages and disadvantages of a multi-touch 3D touch-sensitive tablet

+ no puck or stylus to get lost, broken, or vibrate out of position.
+ they can be moulded so as to make them easy to clean, therefore making them useful in clean environments like hospitals, or dirty environments like factories).
+ templates can be placed over the tablet to define special regions and, since the hand is being used directly, these regions can be manually sensed, thereby allowing the trained user to effectively "touch type" on the tablet.
- the fast scanning multiple-touch-sensitive input tablet is a prototype; so the effectiveness of this device may be limited in other (not yet tested situations).

2.8.1.3 Trackball with contextual motor feedback (cmf)

definition: trackball device which combines directness of control with manipulation comfort. By supplying corrective force feedback as a function of the current display structure and momentary cursor position, the user's movements are guided towards preferred cursor positions; thus force feedback can improve the expressiveness of the trackball by blocking those movements that are in the current context of no use, and by actively pulling the cursor and trackball towards an 'active' region (Goossens, 1992): applying *feedforward.*

USr: Tactual
SUr: Visual and Tactual

2.8.1.3.1 Advantages and disadvantages of the trackball with cmf

+ as a result of the higher expressiveness, people with small motoric imprecision can benefit from force feedback: higher expressiveness helps to make the required adjustments by providing the user (fast) tactile feedback.
+ the effectiveness of the input device can be influenced:
. the performance (in terms of movement time and errors) can be increased.
. by applying force feedback the 'feel' of the input device can be influenced . by tuning it to create that feeling the user likes.
+ force feedback is also expected to decrease the load demanded by the visual modality in eye-hand coordination.
- the input device is not yet tested in realistic situations where we are dealing with multiple targets (e.g. multiple softbuttons or a menu), so the stated effectiveness of this device is only applicable for pointing to a single softbutton.

- feedforward can disrupt the task the user planned to do.

2.8.1.3.2 Applications

Brochure on interactive communication products (1991):
"Currently the trackball with cmf exists as a laboratory system and contains a single example display with soft keys, demonstration menus, slide bars, and a maze tracking exercise for studying speed-accuracy trade-offs in cursor manipulation. However many interactive applications can benefit from the trackball with cmf. Cmf can be applied for instance:
. In text-and graphics-editors in the office environment.
. For arm chair control of TV and CD-I systems.
. In CAD systems.
. For robust control of car audio systems.
. To add the tactile modality in 'virtual reality' applications.
According to Goossens (1992) the trackball with cmf is more robust for deficiencies in eye-hand coordination."

2.8.1.4 Foot-operated input devices:

the foot is used as a human input device(; foot controls are popular with rock music performers, dentists, medical-equipment users, car drivers, and pilots).

Footmouse
definition: a foot-operated cursor control device that consists of a metal pedal approximately 11.5 cm square (4.5 in square; Harriman, 1985). Its rubberized surface pivots so that the foot can depress the pedal at its top, bottom, left or right edge. Each press moves the display cursor one row or column in the selected direction; continued pressure toward an edge repeats the cursor movement at a constant rate.

USr: Tactual
SUr: Visual

Other foot-operated input devices are:
- foot switches as an alternative to frequently used keys.
- moles (Pearson & Weiser, 1986).

2.8.1.4.1 Advantages and disadvantages of foot-operated input devices

+ during typing, the hands never have to leave the alpha keyboard for cursor positioning; thereby permitting the hands to deal with the remaining aspects of the task more efficiently.
- restricts the posture of the operator, and either requires that one foot be on the control when it is not in use, or, to prevent accidental activation requires that both feed be some distance from the control.

2.8.1.4.2 Applications

- the footmouse offers a solution for tasks in which it is undesirable to assign a hand to cursor positioning tasks.

2.8.1.5 Gesture-based input

definition: operator gestures are used as a basis for input; just as touch screens are used for small screens, a gesture-based system may be used to point with a large screen display.

2.8.1.5.1 Types

• *Data-gloves*
definition: devices that consist of a lightweight cotton glove worn on the hand of the user, which is equipped with a variety of sensors that detect hand, wrist and finger movements and provide tactile feedback simulating contact, hardness, and surface texture. The user wears the glove and interacts with "virtual" objects on a computer screen or objects manipulated by a robotic hand controlled by glove movements (Zimmerman, Lanier, Blanchard, Bryson, & Harvill, 1987).

USr: Tactual
SUr: Visual

Applications of data gloves

- transcription of sign language for the handicapped.
- manipulation of objects in a simulated 3D environment.
- control of robotics hands in environments hostile to human life (for example, outer space, undersea, or areas with high radiation.

• *Data glove in combination with voice input* (Weimer & Ganapathy, 1989): the user interacts with a simulated 3D world on the screen by talking and gesturing. The hand gesture language is based on the assumption that speech is often more efficient than gesture and that, in normal discourse, people only use gestures to augment speech for those few things that are more easily gestured than spoken. *Voice input* is used primarily for defining broad actions, such as "translate", "rotate," and "scale".
Hand gestures select objects to operate on and control the details of the operation.

USr: Tactual and Auditory
SUr: Visual

Applications (tasks) for the data glove in combination with voice input

- Operating a virtual control panel.
- Selecting objects or geometric figures.

- Translation, rotation, and scaling of objects.
- Perturbing control points of bicubic patches.
- Defining space curves and swept surfaces.

2.8.1.5.2 Advantages of gesture-based input

+ gesture-based input offers a natural and unobtrusive means for input of object designation and manipulation actions typically performed by the hand directly; thus the capability of the hand to simultaneously move, rotate, and grab can be exploited to flexibly and efficiently accomplish tasks requiring the manipulation of displayed objects.
- precision is low and response is slow.

2.8.1.6 Eye-controlled input:

several groups of researchers have begun to investigate eye movements as a method of (computer) input: Calhoun, Janson, and Arbak (1986); Glenn, Iavecchia, Ross, Stokes, Weiland, Ross, & Zakland (1986); Ware & Mikaelian (1987).

2.8.1.6.1 Types

• *Eye tracking device*
definition: gaze-detecting controllers to assist the handicapped (Jacob, 1990). A description and evaluation of an eye-tracking device is reported in Ware and Mikaelian (1987). People fixate on visual objects by moving the eye to cause the object to be imaged on the foveal region of the eye, where visual acuity is the highest.

USr: Visual
SUr: Visual

Implementation issues of eye-tracking devices

<u>The provision of locational feedback</u>
Feedback can be either continuous, such that the computed point of attention is always shown on the display, or discrete, in which a target is highlighted only when the gaze is near or on the target.

<u>The method of confirming selections</u>
Work by Calhoun et al. (1986) and Ware and Mikaelian (1987) suggests that a conveniently located physical button should be used to designate an item on which the eye has fixated.

<u>Target size</u>
Work by Ware and Mikaelian (1987) suggests that target sizes should subtend at least a degree of visual angle.

• *Experimental eye-tracking system as part of a larger system that combines eye-tracking and voice-recognition for input.* Users control the cursor with eye-tracking and issue commands with voice input (Glenn et al., 1986).

USr: Visual and Auditory
SUr: Visual

2.8.1.6.2 Advantages and disadvantages of eye-controlled input

+ eye-controlled input can reduce workload, free the hands to perform other tasks, and eliminate time-consuming operations of locating, grasping, and moving manual input devices.
- the eye's line of sight only approximates the true point of visual attention because a number of involuntary eye movements take place even while the eye is attempting to fixate on a point.
- Most currently available eye-tracking technologies also require that the user wear special equipment, and thus they may be intrusive.

2.8.1.6.3 Applications

• for handicapped users.
• for users constrained by g forces (e.g. in space).
• for high-frequency users who would suffer from fatigue in long-duration manual manipulation tasks.
• for users whose hands need to be free for other activities.
• attractive for item selection and target tracking tasks because it uses eye movements inherent in these tasks as the control input.
• not well suited to tasks involving very small targets.
• the technological complexity and cost of current eye-tracking technologies make eye-controlled input impractical for any application in which rapid hands-off input of spatial information is not of paramount importance.

3. Further readings

A broad range of input devices have been classified by Foley et al. (1984) according to the graphic subtasks they were capable of performing. Furthermore, Buxton (1983) and Baeker et al. (1987) have proposed a taxonomy of input devices classified according to the physical properties and the spatial dimensions they sense. These listed devices have been reclassified by Card, Mackinlay and Robertson (1990) in order to generate a single systematic framework "that can be used both to classify nearly all existing devices and to generate ideas for new ones not yet invented."

4. Conclusions

In the preceding discussion some aspects of interaction devices were discussed; these can aid in initial decisions about which devices are appropriate for a given user population, task, environment and hardware configuration. However, as mentioned before, these technologies should not be applied blindly because they *seem* better. Regardless of the type (or state of the art) of interaction devices, the different characteristics that influence their relative usability for different tasks, environment, and users should be determined. Only after these have been carefully considered (e.g. in a 'user study'), an appropriate interaction device can be selected.

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