Chapter 2:

AN ILLUSTRATED TOUR

Introduction

The purpose of chapter is to provide a quick introduction to a range of input devices. It will give the reader a sense of how diverse the range of devices is, both across and within device categories. In it, devices are organized primarily by their physical and mechanical properties. This is the way in which they have mostly been discussed in the literature (for example, Newman & Sproull, 1973; Foley & van Dam, 1982; Sherr, 1988; MacKenzie, 1995). While this is a good start, much of the rest of this book is to build on this foundation, and try and balance our discussion of technologies with one that focuses more on the user, intent, and context. As Flaubert said:

> *Le bon Dieu est dans le detail. (God is in the detail.)*

Otherwise, we could probably finish the book at the end of this chapter!

The plan for the moment is to run fast and lose. The idea is to get a taste of things. Breadth rather than depth is the point. We just want to establish a broad common set of references as quickly and as possible. Hopefully this will help motivate and equip the reader to enthusiastically pursue the chapters that follow.

Now, on to our tour[1].

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[1] To help in this process, as a companion to this book, and especially to this chapter, I have created two additional resources

The Buxton Collection: A website that presents photographs, written commentary and additional documentation on a collection of interactive devices that I have assembled over the past 30 years. http://research.microsoft.com/en-us/um/people/bibuxton/buxtoncollection/

A Directory of Sources for Input Technologies: A list of names and addresses of suppliers of input technologies. While on the one hand I have not kept this completely up to date, hopefully it is still of use:

> *http://www.billbuxton.com/InputSources.html*

Text Entry

Right away, think about the title of this section: "Text Entry." Now, what comes immediately to mind? For most people, the assumption is likely that we are now going to embark on a discussion of various types of keyboards. But pay attention to the subtle, but important, bias that language can have. Like many (if not most) publications on input, we could have used a *device-centric* heading, such as "Keyboards," rather than the *task-centric* heading of "Text Entry." The latter forces us to consider the broad spectrum of text entry techniques and technologies, and more importantly, forces us to recognize that there are alternatives, and that for designers and users alike, there are choices to be made.

This matter of choice, and more specifically *informed choice,* is extremely important to improving the state of the art. I don't know where I heard it, or where it came from, but one of my favorite definitions of design is:

> *Design is choice.*

What I like about this seemingly simple definition is that it opened up for me a way of articulating where and how science and creativity can be applied to the process. This I put as follows:

> *Design is choice. There are two places where theory, science, experience, invention, innovation and art can be applied:*
>
> 1. *In the generation and enumeration of the set of things from which one chooses.*
> 2. *In the selection, creation and use of the heuristics which one utilizes in making the choice from among those options enumerated.*

This may seem overly simplistic. But it such "simple" things that have guided me in most of my work, including the mindset behind this book. How does it help? Well, I would argue that half of the bad design that I have seen is due to the limitations of the scope of the brief, or what one drew from. The other half has been largely due to the designer making decisions on incomplete, or the wrong information.

At a very practical level, I use this characterization of design all the time as a reminder to search for other alternatives and ways of thinking. And one of the main purposes of this book is to help the reader better understand the range of options that are available, and provide the tools (by way of technologies, theories and techniques) to make better choices.

Which brings us back to text entry, and a look at the range of choices there (we will have to go deeper into the book to build the tools to understand the larger implications of some of these alternatives, and how we might best exploit them).

What we will see are alternatives that include:

- *keyboards:* conventional and otherwise
- *speech input*
- *written input*: using fingers or styli through printing, cursive writing or shorthand
- *graphical keyboards*: using devices as diverse as touch screens, eye trackers, joysticks and trackballs)

The reader is encouraged to explore this page and its links in order to get an even broader sense of the space covered in this chapter.

- *sign language*: using video cameras or instrumented gloves
- *computer algorithms*: where it guesses the rest of your “sentence” and completes it for you.

Each is likely best for something and worst for something else. The trick is in finding the optimal match between the affordances of technology and the demands of the application (including context, users, etc.).

Refs: virtual keyboards on screen activated by touch (sears, Shneiderman, etc) or stylus (MacKenzie, etc), or character recognition (the world) or speech, or special strokes (eg Venolia, Goldberg, etc.) Perhaps talk about keyboards, use this as an early opportunity to highlight issue.

- Add tilt-type
- Seibel, R. (1972) - good background (Van Kott & Kinkade)
- Gentner (1981)
- Montgomery (1982)
- Norman & Fisher (1982)
- wipe keyboard. IBM? Find source. More recent: 5625354 and its diagram on <www.patents.ibm.com >. The keys are hexagonal, in a honeycomb pattern
- Noyes (1983)
- Potosnak (1988). Good recent review
- Roberts, M. & Rahbari, H. (1986); the *Cipherwriter,* an approach to key board entry that uses trades off number of keys for number of keystrokes. At any time, only 8 characters are available (as displayed on the screen): one under each of the 4 fingers of each hand. The full caracter set is laid out in rows in an 8 column format. The thumbs are then used to move up and down, selecting the row containing the desitred character, then one of the 8 fingers used to select one of the 8 characters in that row.
- Rumelhart & Norman (1982)
- Butterbaugh, L.C. (1982). Evaluation of alternative alphanumeric keying logics. *Human Factors*, 24, 521-533.
- Shaffer & Hardwick (1968).
- reactive keyboard: Darragh, J., Witten, I. & James, M. (1990)
- re speed of text entry, see (also discuss in marking chapter?):Devoe, D. (1967). Alternatives to handpriinting in the manual entry of text. *IEEE Transactions on Human FActors in Electronics,* 8(1), 21-32.
- for survey of keyboards see: Montgomery, 1982
- Brown, C.M., 1988. Comparison of typing and handwriting in "two finger typists". *Proceedings of the 32nd Annual Meeting of the Human Factors Society*, 381-385
- Zipp, P., Haider, E., Halpern, N., & Rohmert, W. (1983). Keyboard design through physiological strain measurements, *Applied Ergonomics,* 14(2), 117-122.
- for study of size on typing speed/accuracy (1h & 2h): Wiklund, M., Dumas, J. & Hoffman, L. (1987)
- for voice vs keyboard, see: Johnson et al (1986)
- kbd design: Alden, Daniels & Kanarick (1972).
- identity authentication based on keystrokes: see Joyce & Gupta (1990)
- Cooper 1983 for good overview, including chapters by
- Gentner et al
- Gentner
- Norman &Rumelhart
- Grudin

We can begin to get some perspective on the range of input devices available by examining some alternative methods for entering text into a computer. A point to note is that each of the following devices is plug-compatible with conventional typewrite-type ascii keyboards. While the computer sees them all as the same thing, this is certainly not true for the user.

Figure 1: The Maltron keyboard: radical design sculpted to fit shape of hand and fingers.

Figure 2: The Writehander (NewO Co.): a chording keyboard for one-handed text entry.

Figure 3: The TASA Keyboard: a touch-sensitive keyboard with no moving parts.
Useful In environments which must be quiet (such as a recording studio), those which are very dirty (such as factories), or those which are very clean (such as hospitals).

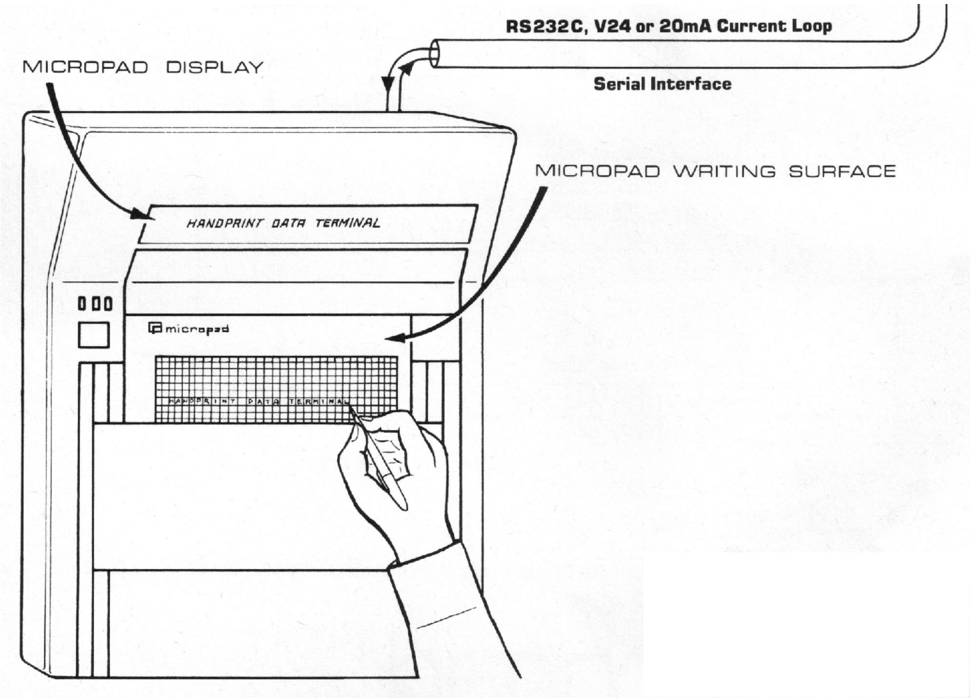


Figure 4: Micropad Tablet:
This is an example of hand-printed character recognition technology circa 1979. One must print each character In a specific box. One writes with pencil on a pressure sensitive pad, over which the paper is laid. (Micropad Ltd., Dorset, UK).

Mice

Case study discussion of industrial design to come. For background on industrial design of mice, see:

- Abernathy & Hodes (1987)
- Hodes & Akagi (1986)
- Hodes (1987)
- Lewis & Alfonso (1989)
- Verplank & Oliver (1989)
- Barket, Holtzman, Olin & Rosin (1987) shows how similar approaches have been used to develop other devices.

For a description of mechanical/electronic functioning, see Alford (1990) or Sherr (1988).

In the beginning …

In the early 1960's, what was to become an extremely influential project was begun at the Stanford Research Institute in Menlo Park, CA. This was a kind of research "think tank", and the basic ambition of the project in question was to demonstrate how computers could serve to augment human intellect. Articulating the problem in this human-centric way, where the technology is viewed as a cognitive and social prosthetic, is novel even today. At the time it was simply revolutionary.

This work is covered in more detail in Chapter 6, in the discussion of chord keyboards. For the moment, take the above by way of a brief introduction to the inventors of the mouse – the first one of which is shown in Figure 5.

Figure 5: The Original Mouse by Engelbart and English.

Macintosh Mouse Model M0100 (1984)

Apple mice always had only 1 button. The idea was that this simplified the user interface by avoiding confusion about what button to push. There is a strong argument, however, that this just pushed the complexity elsewhere.

The Xerox 6085 “Viewpoint” Mouse (1985)

The mice released with the Xerox Star 8010 workstation and its successors, like the 6085, all had 2 buttons, despite the earlier research mice having three. This was to reduce confusion. They didn’t go to 1 button like Apple, however because their studies showed that any reduced confusion came at the expense of added selection errors. (Johnson, Roberts, Verplank, Smith, Irby, Beard & Mackey, 1989).

Mouse Systems M1 Optical Mouse (1982)

This was the first commercially available optical mouse. Like most mice at the time, it had three buttons. Unlike today’s optical mice, the M1 needed a glass pad for optical sensing.

UNITA Unity New Input Accessory (1996)

Incorporates a 10-key pad with function keys and Windows 95 keys. This Mouse let you input numbers and access function keys. The device comes with Ctrl, Alt, Tab, Return, Mode Change, and Shift keys.

Small Talk Mouse Phone (

Somebody had to do it! Yes, this mouse doubles as a phone and the keypad for dialing is on the back.

The "Mighty Mouse": The first scrolling mouse

This mouse developed jointly by NTT, Japan and ETH, Switzerland (Ohno, Fukaya & Nievergeld, 1985). It is the first scrolling mouse. It had five keys (one for each finger and the thumb) as well as a thumb wheel. The thumb and index finger keys were spring-loaded analogue keys that could either be binary, if activated by a fast click, or continuous analogue controls if pushed slowly. In addition, the thumb key could be slid forward and backward to change mode. The other 3 keys were binary switches. In contrast to modern mice, scrolling was not done with the wheel, but with the thumb key. Clicking the thumb key moved the document forward or backward a page at a time, while pushing gently on the thumb key smoothly scrolled the document or list forward or backward at a speed proportional to the pressure. The direction of paging and scrolling depended on if the thumb key was in the forward or back position. There were at least two versions of this mouse built and used.

Apple Macintosh mouse with thumb-wheel

Mice can be configured to sense more than motion and button presses. This prototype mouse developed by Dan Venolia (1989; 1993) of Apple has a thumb-wheel mounted on the side. In 2D applications the thumb-wheel was used to scroll through documents, pull-down menus, etc. In 3D applications it was used to move the tracking symbol in the "z" dimension.

Chordless Mouse with Scroll Wheel from Logite

This is an example of a cordless mouse. Useful in situations such as a conference room with large screen projection. Is also an example of including a 1DOF finger operated controller between the buttons for scrolling, etc.

A4 Tech Full Control Wireless Optical Moust

The model RP-649 mouse has 2 scroll wheels. One is for scrolling up-down, and the other for scrolling left-right or for zooming.

Scrollpoint Mouse by IBM

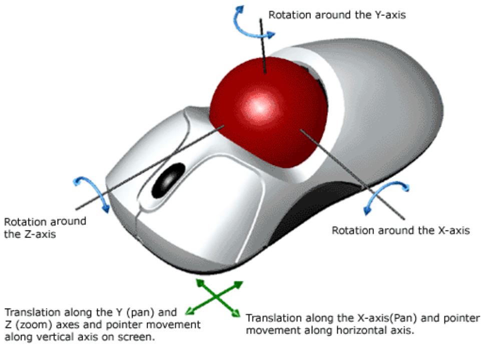
This mouse uses a miniature 2DOF isometric joystick for 2D scrolling tasks.

Fujitsu Takamisawa ScrollPad Mouse (1998)

This is the first commercially available mouse that I am aware of that incorporated a touch-sensitive pad to support scrolling. What is most impressive is that it not only supports vertical and horizontal scrolling, it seamlessly supports 3 modalities of doing so, by tapping to step (comparable to pressing an arrow key), brushing in the desired direction by finger motion, and constant rate control, by touch and hold, or brush and hold.

IOGEAR Webcruiser Mouse with 2D Trackball

Here, 2D scrolling is enabled by means of the 2DO trakball that is mounted on the back of the mouse.



Inspector 6DOF Mouse by Dimentor

This is a hybrid scrolling mouse / 3DOF trackball. In to the scrolling wheel, the mouse has a trackball mou its back. The trackball is designed in such a way tha be rolled forward/backward, left/right, and twisted clockwise/anticlockwise, thereby offering 3DOF. Whi providing access to 6DOF in total, physical ergonomi dictate that not all can be accessed simultaneously, a with equal dexterity, an d to take full advantage of the of freedom may require operating the device with two

Tactile Mouse with Limited Force Feedback

A prototype mouse with tactile feedback and limited force feedback developed by the Industrial Products Research Institute (IPRI) in Tsukuba, Japan (Akamatsu & Sato, 1992; Akamatsu, Sato & MacKenzie, 1994). Tactile feedback is provided in a manner similar to that used in the "flying mouse, shown above. In this case, there is a single "pin" driven by a selenoid that can rise and fall. This is visible in the illustration. The device uses a metal mouse pad, and has a magnet mounted in its body. Therefore, by changing the force of the magnetic field, the resistive force encountered in moving the mouse can also be controlled. (Photo: Dr. Motoyuki Akamatsu)

FEELit Mouse from Immersion Corp.

A mouse that is an output device as well as input. The mouse is connected to mechanical arm that can be controlled by two motors, thereby providing force feedback which can be used to give a sensation of “touching” objects, such as icons or geometry. Force feedback differs from tactile feedback in that force “pushes back” whereas tactile feedback is simply a vibration or contact that lets you know that you have touched something.

Digitizing Tablets

Tablets generally return 2 dimensions of information. The values returned are generally absolute values in a 2D coordinate space. Tablets vary in size, resolution, and technology. Of special interest is what type of physical control the user manipulates. These generally fall into three categories: *stylus*, *puck,* and *touch*. However, I will treat touch tablets as a separate category. While there are certainly touch tablets, they have evolved from a tradition of interacting with a graphical user interface, rather than one of accurately digitizing points from a map, or creating accurate CAD data. Yes, all three are now used in general interaction; however, digitizing tablets are based on a foundation of very precise location-based digitization – a characteristic not generally shared with touch tablets.

Figure 6: Tom Ellis, one of the inventors, using the RAND tablet. In his right hand is the tethered stylus, and on the screen a series of graphic lines. (Photo: Computer History Museum Collection, Catalog Number: 102710338). (Note: need to secure permission.)

To the best of my research, the first digitizing tablet was the Rand Tablet, developed in 1963 for Lincoln Labs, under a contract from DARPA. It was used to great effect on a number of pioneering projects, connected to Lincoln Lab's TX-2 computer, designed by Wesley Clark.

Figure 7: Two Pucks and a Stylus (GTCO Corp).

Pucks & Styli

The stylus is good for fine drawing and delicate motion (uses fine muscle groups of fingers, like a pen). However, they are harder to pick-up, and roll out of position when put down. A stylus generally has a switch in its tip that can be activated by pushing down on the stylus body. In some, the tip may not be a switch; rather, it may sense pressure continuously. If more buttons are required, auxiliary keypads are often provided, typically operated by the other hand.

Alternatively, (or as well) some stylus' have one or more “barrel switches” on the side. These can be activated independently from the tip switch, using the index finger; however, there is still contention as to whether these are a good idea or not. As always, the answer is, “It depends,” – on the industrial design, application, and context.

Pucks vary greatly in design. The number of buttons is one consideration. A puck for digitizing or coding an X-ray, or geological data, may have several buttons to provide efficient access to key functions. Such pucks are generally not ideal for typical mouse-type functionality. These pucks typically have “cross-hairs” embedded in a transparent extension of the puck body (as shown in the photo). This provides more accurate placement of the puck over the specific point of graphical image being digitized, or coded.

Other pucks may be indistinguishable from a mouse. These are typically intended to be used where what is being pointed at appears on the screen, rather than on paper, or some other medium, on (or under) the tablet itself.

However, while such pucks *look* like a mouse, they don’t *feel* like one when moving the cursor on the screen. That is because the tablet is a *position* rather than *motion* sensing device. If you carefully lift a mouse up, and then put it down at a different place on your desk, the screen cursor does not move. With a puck – which may look exactly the same – the cursor would jump from its current position to the same relative position on the screen as the puck was newly placed on the tablet.

Without getting ahead of ourselves, I might add that a mouse can never do the same thing, yet, with appropriate software, digitizing tablets can function in a mode where the puck *does* behave like a mouse – in which case the tablet functions as an expensive mouse pad!

Wireless Tablets & Pucks

Initially, tablet pucks and styli were all tethered. It was only in the mid-1980s the cord was eliminated and the devices became wireless. To the best of my research, the first tablet with a wireless stylus was the Wacom WT-460M, shown in the photograph to the left, launched in January 1984.

Besides being wireless, nearly all styli today also have pressure-sensitive tips. Tablets are becoming thinner, and some manufacturers (Scriptel, for example), have offered transparent tablets in order to facilitate digitizing paper maps and drawings, for example, by placing them under the tablet (sometimes with back lighting), and tracing their contents with the stylus or puck.

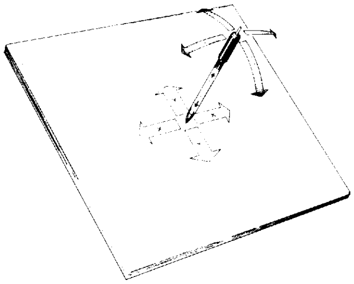


Figure 8: A Tilt-Sensing Stylus (GTCO Corp)

Tilt Stylus: Stylus as "Joystick"

The diagram shows how sensing stylus tilt is much like having a mobile joystick. If you are wondering why you might want this, or automatically assume that this would be too difficult to control, just think about how an artist subtlety uses tilt, in combination with pressure and movement, to obtain subtle control over the lines drawn, or their calligraphy. While it may be difficult to control all dimensions independently, it really depends on the quality of match amongst the human's motor-sensory skills, the technology, and the application. No technology can overcome bad design decisions.

MAX 6DOF Stylus from Terminal Display Systems (TDS)

The stylus illustrated, *which was available in 1988,* sensed displacement in X & Y, tip pressure, tilt in X & Y, and stylus barrel rotation. It afforded being rolled over the surface of the tablet to flatten part of a graphical surface, for example. It also had an accelerometer impulse switch, as well as buttons. (Photo: Terminal Display Systems)

5'x10' Non-Backlit Digitizing Tablet from Altek

Tablets may be large and free standing, such as this one, or built into the keyboard. From the user's perspective there may be a greater difference between two different tablets than between using a mouse or a tablet. (Photo: Altek)

Flexible *Roll-Up* Tablet from GTCO

This type of tablet can be rolled up for easy transportation when used with a portable computer in the field. This model supports wireless pucks and styli. (Photo: GTCO)

(Photo: note credit for left image needed. Source: http://cutiedevil.com/fairchild-picture-airbrushed-flames/)

The Airbrush: There is still a way to go …

Despite the advances in digital pen/stylus technology, we have still not reached the bar set by a conventional airbrush. While the Wacom airbrush stylus shown in the photo has the form of a real airbrush, we still don’t have the ability to sense the position, tilt, and angle of the airbrush relative from the artwork, while also sensing the distance from it – a critical factor in determining the size of the ink pattern, as well as the density of the ink. Furthermore, the software of few, if any airbrush programs enable the tilt of the pen to determine the conic section which defines the shape of the ink pattern.

Many argue that users can't handle all of the dimensions of some of the styli illustrated above. The airbrush shows that those styli don't provide *enough* dimensions!

Touch Tablets

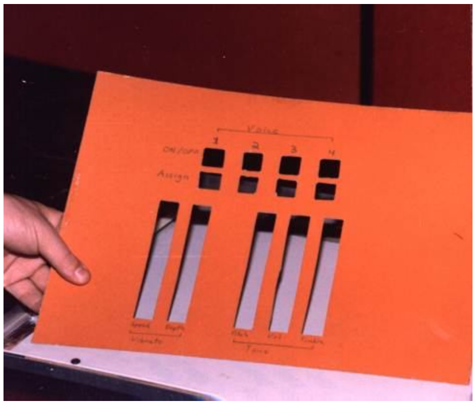
We will discuss this class of device further in Chapter 5*: Case Study 1: Touch Tablets..*

- Touch tablets come in various sizes and forms. This one, from Cirque, is free-standing and sits beside the keyboard. It senses if and where you are touching. It also has buttons on the side to provide the equivalent of mouse buttons and function keys.

- Because of their low profiles, touch tablets can be mounted in keyboards. This one from Cirque is an example. Many laptop computers do something similar..

- In this prototype, the *padmouse* (Balakrishnan & Patel,1998), the touchpad is integrated into a mouse. One can use the mouse for conventional pointing tasks, while simultaneously using the touch pad for tasks such as scrolling in a document, or scaling an object being dragged or selected by the mouse. A similar device which is commercially available is shown in Chapter 5.

- Casio PF-8000 Databank: This touch pad is integrated into a pocket calculator/data bank. It had a simple character recognizer built in which permitted names and numbers to be by “writing” on the touch tablet with the finger. Being released in January of 1980 (for $69.95 US), it was way ahead of its time..

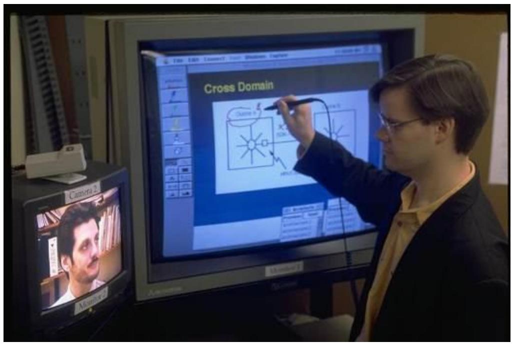


- Templates can be placed over touch tablets (this example from Buxton, Hill & Rowley, 1985, is discussed in Chapter 5). If the template has raised ridges, one can "touch type" on the device. That is, the ridges of the template permit the user to feel the boundaries of the virtual device and thereby function like the frets on a guitar. Consequently, the trained user can work without diverting the eyes from the screen. This is in contrast to tablets that have markings printed right on them, such as the Casio Databank shown in the previous figure.

Touch Screens , Light-guns and Light-pens

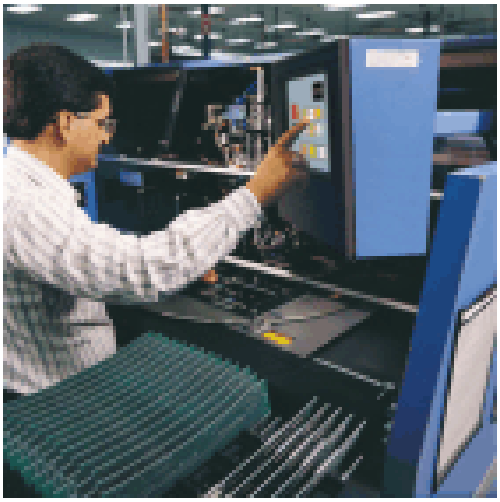
- Light-gun invented ca. 1950 by Robert Everett for the Whirlwind computer at Lincoln Lab (Fallon, 1998).
- Light-pen developed for the TX-0 computer by Ben Gurley at Lincoln Lab (Gurley & Woodward, 1959; Fallon, 1998).
- Benel & Stanton (1987)
- Penna, D.E. (1984)
- Beringer & Peterson (1985)
- Hall, A., Cunningham, J., Roache, R. & Cox, J. (1988)
- Pfauth, M. & Priest, J. (1981).
- Parng & Ellingstad (1987)
- Potter, R., Berman, M. & Shneiderman, B. (1989).
- Potter, R., Shneiderman, B. & Weldon, L. (1988).
- Schulze, L.J.H. & Snyder, H.L. (1983). comparison of different touch technologies. make table from results?

- sears & Shneiderman (1991).
- Shneiderman, B. (1991)
- McClelland, D. (1990). describes surface wave technology
- Magel 1993 - gives overview of technologies
- Sears
- Sears, A., Revis, D., Swatski, J., Crittenden, R. & Shneiderman, B. (1991).



Lightpen With Large CRT as Whiteboard

Using a large CRT as a shared electronic whiteboard in a videoconference. Participants are able to use a lightpen draw on and interact with the shared data on a large CRT, while see each other on a smaller adjacent CRT. Worth noting is that lightpens work with rear projection CRT (not LCD) rojectors. Hence, any rear projection system employing a CRT projector can be easily converted into a “flat panel electronic whiteboard” using a lightpen. (Photo: Ontario Telepresence Project).



Touchscreen in Manufacturing

Here a touchscreen is used in an manufacturing context. The display and the “console” are integrated, saving real-estate. (Photo: Carroll Touch Sytems).

Touchscreen with Scanner & LCD from Panasonic

This prototype system shown at a tradeshow in Japan in 1996 illustrates how one can support novel (and often appropriate) approaches to interaction by “mixing and matching” commercially available technologies. This system lets you layout the photos on a page more like you do on your fridge rather than how you do so currently on your web page or in a page layout program.

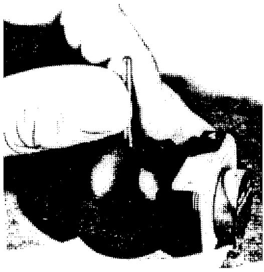
The system consists of an LCD display with a sheet of glass equipped with a touch screen in front of it. Between the LCD display and the glass space for a scan bar, just like on a conventional document scanner. One just holds the document on the touch screen over where you want it to appear on the LCD. The touch screen senses the contact and the scanner digitizes it. (Photo: Buxton)

In these examples, we see that the gross motor control used in operating a light pen and touch screen is very similar.

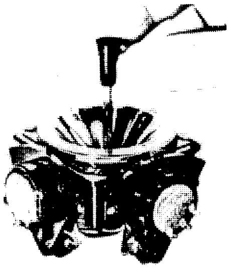
Touch Screen Refs:
Benei & Stanton (1987)
Beringer & Peterson (1985).
Herot (1977)
Minsky (1984)
Harison & Hudson (2012)
Pfauth & Priest (1981)
Pickering, J.A. (1987)
Potter, Berman & Shneiderman (1989).
Potter, Weldon & Shneiderman (1988).
Sears & Shneiderman (1989)
Schulze & Snyder (1983): compare different touch technologies.

Lightpen Refs:
Hatamian (1986)
Hatamian & Brown (1985)

Joysticks



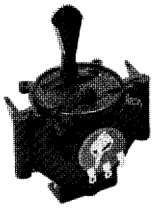
Floating



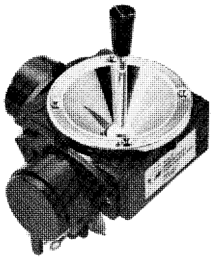
Self-Returning
(Measurement Systems)

Isometric

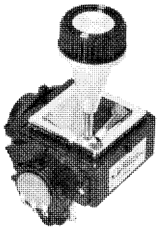
There are 3 main classes of joystick: *floating, spring-loaded self-returning*, and *isometric*. Floating joysticks give absolute, position-sensitive coordinates. Self-returning and isometric joystick give relative coordinates (offsets). The magnitude of change for self-returning joysticks is generally determined by position: change is proportional to distance and direction of the shaft's offset from centre. For isometric joysticks, the relative change is determined by direction and magnitude of the force applied to the shaft.



1D



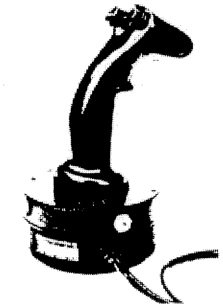
2D



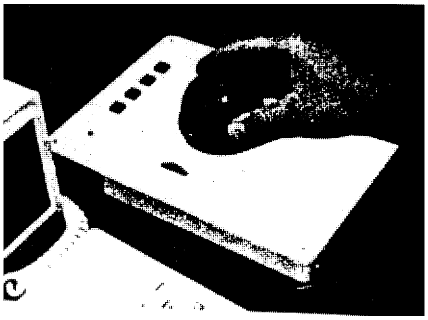
3D

(Bolt Industrial)

Joysticks also vary by the number of dimensions of information that they provide. Those in the figure above return 1, 2, and 3 dimensions, respectively. The third dimension of the 3D stick is obtained by rotating the shaft.

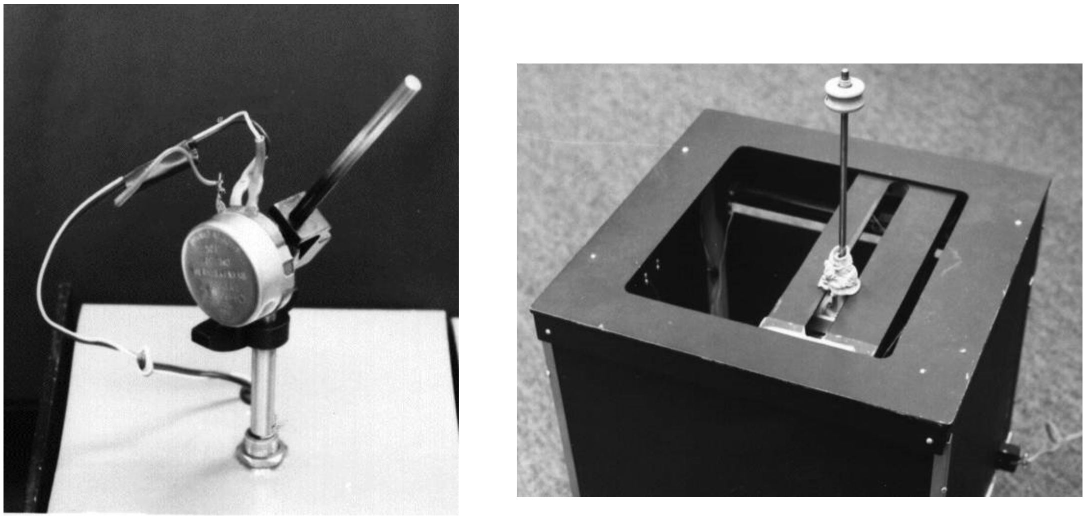


4D Joystick
(Measurement Systems)



6D Joystick

The joysticks in the figure above return 4 and 6 dimensions, respectively.



Two alternative joystick designs from the University of North Carolina at Chapel Hill. (Photos James Lipscomb)

The 2D joystick on the left is position sensitive, but senses rotation of the vertical shaft and vertical motion of the horizontal one. The angles of motion were designed to correspond to the angles of the graphical objects to be manipulated, thereby obtaining improved stimulus-response compatibility. The 3D joystick on the right is characterized by its size, and the fact that the third dimension is obtained by sliding the shaft up or down, much like a butter churn, thereby providing position sensing in all three dimensions. (Britton, E., Lipscomb, J. & Pique, M. (1978)

Include images & discussion of J-key Douglas, S. & Mithal, A.M. (1994). and the IBM pointing stick (Selker & Rutledge).

Armatures

Armatures are input devices that use a set of jointed levers for input. A will be seen in the examples, they come in a wide variety of types, and can be used in a wide variety of ways. But what each has in common is that each joint is instrumented so that the computer can sense the joint angle. By also knowing the length of each member, the computer is able to use forward kinematics to calculate the position of the end of any arm segment, relative to some base reference point.

In one way, you can think of joysticks as armatures having just one segment. In fact, the genetic link between joysticks and armatures can be seen in the last example in the previous section, which is a two-segment joystick developed at the University of North Carolina at Chapel Hill. Is it a joystick or an armature? The answer is, "Yes."

***Microscribe* from Immersion Corp.:**

This armature was originally designed to digitize 3D objects. In the photograph, the user is sampling locations on the surface of the plaster cat, and the coordinates thus derived are being used to construct the surface geometry of a computer model, as shown on the computer screen.

However, if the device can communicate the coordinates of the endpoint as a continuous stream, the device can be used as a 6DOF input device.

The *Monkey* Digital Interface Design

This device differs from the former in a few ways. It is obviously mode complex, having many more segments and joints. It is used in animation for posing characters. It's strength and weakness is that when used this way, it must resemble the character being animated. Thus, while this form works well for bipeds, it would have to be reconfigured to be used to animate a dog, for example.

Unlike the *Microscribe,* the joints are not "lose." There is enough friction for them to stay in place unless adjusted by the animator.

The *Animation Station* from PuppetWorks

The PuppetWorks technology is similar to that of DID in the sense that it consists of a “Mechano Set” like set of arms and joints that can be assembled in different forms. They differ mainly in the specifics of cabling, mechanical design, and how joint angles are sensed.

In this configuration, only three arm segments are employed. This configuration is closer to that of the *Microscribe*. The main difference in feel is in the friction of the joints. With the *Microscribe,* these are loose. With the *Animation Station* and the *Monkey,* these can be adjusted by the user to be as tight or lose as the user desires.

Coupled with a “clutch” type mechanism, this type of configuration, including the *Microscribe,* can function as a more general 3D input device. The armature need not look like the thing being controlled, and it can ideally be dynamically attached to different points or “handles” on the computer model, as required by the animator.

The *Phantom* from SensAble Technologies

The phantom is an example of placing motors as well as sensors into the joint angles of the armature to create what has been called a *haptic* or *force feedback* device. Through the motors, the device is an output as well as input device.

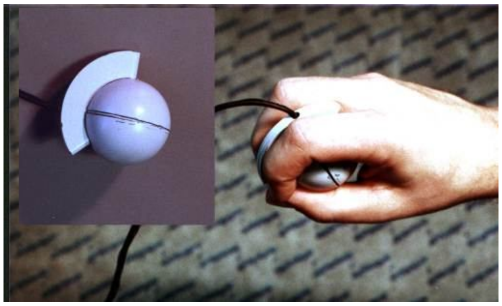
Three different versions are shown. Each lets you “feel” the point of contact with the surface of the computer model. We will discuss this class of device further in Chapter 15*: The Future and Emerging Potential.*

Flying Mice, Bats, etc.

Mice work on the flat. They work mainly in 2D. However, much of computer graphics, for example, involves working with 3D data. So, a number of people have designed devices that let you “pick the mouse up off of the table.” Such devices have had a range of forms, number of degrees of freedom, and employed a range of sensing technologies.

The *Bat* by Ware & Jessome (1988)

Ware and Jessome added a “mouse button” and an enclosure to a Polhemus 6 degree of freedom (DOF) sensor (X, Y & Z position, plus pitch, yawl & roll) and did some of the first user interface research on this class of device. (Photo: Colin Ware)



6DOF “Mouse” from Apple Computer

This prototype developed by Dan Venolia was also based on a Polhemus sensor. Note how the sensor is housed in a clam-shell like ball that can be squeezed in order to get the equivalent of a mouse button click (Photo: Dan Venolia).

The *Cricket* from DID

Another form factor for a 6DOF input device.

Car Mouse from Renault

This is an example of the form factor of a device being tailored for a specific task, in this case manipulating 3D models for visualizing automobile designs.

In order to facilitate the user maintaining a sense of compatibility between the orientation of the 6DOF controller and the computer model, the device is sculpted into the form of a generic car. (Photo: Bill Buxton)

The _Flying Mouse_ from SimGraphics

Another approach to a 6D tracker based on the Polhemus 6DOF sensor. This unit is packaged so that - when placed on an optical tablet, it also functions like a regular mouse

The device is interesting in that there was a version that provided tactile feedback by mounting a small array of pins in the index finger button which could rise and fall under computer control. Thus, by having them rise when one comes to the edge of an object, for example, one can "feel" the "contact." (SimGraphics Engineering Corp.)

The _GyroPoint_ from Gyration Inc.

This device looks very similar to the prototype 6DOF “mouse” from Apple, shown above. But appearances can be deceptive. All of the previous “flying mice” have had absolute position trackers in them. The *GyroPoint* has, instead, a gyroscope inside.

It is, therefore, a *motion* rather than *position* sensitive device. By analogy, it is to the previous “flying mice” what a conventional mouse is to a puck on a digitzing tablet. It can’t tell you where it is in absolute terms. Rather, it tells you where it is now relative to where it was before.

One consequence is that this class of device is much cheaper.

Another difference is that this product is also wireless.

Gloves and Hands

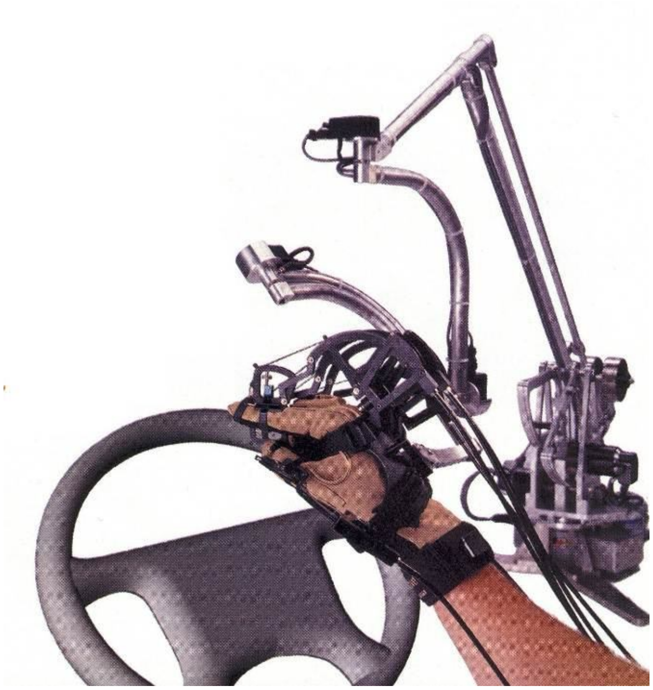
Includes optical and mechanical

CyberTouch Glove from Virtual Technologies

The gloves senses position and orientation of the hand as well as that of the fingers. Position and orientation are sensed by a built-in Polhemus tracker. In addition there are *tactors,* built into the tips of the fingers. When the virtual hand being controlled with the glove come into contact with virtual object in the scene, these give tactile (as opposed to force) feedback to the user.

A Prototype Force Feedback Hand Controller

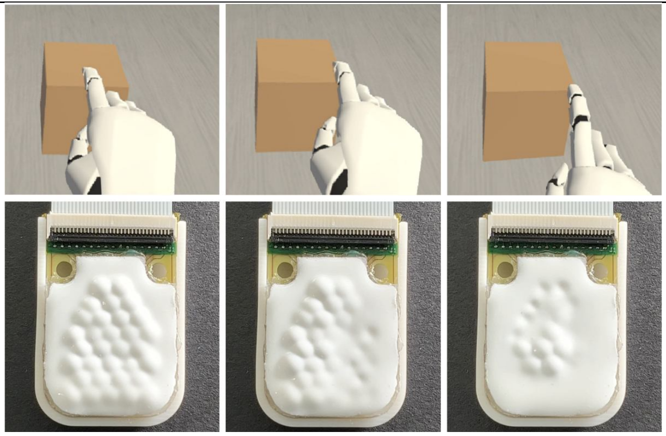
A force-feedback hand controller developed at the University of Tscuba in Japan is shown (Iwata, 1990). The device is a stationary exo-skeletal mechanism which gives force feedback to multiple fingers. The figure shows how the user sees the graphics display through a mirror so as to maintain compatibility between where the eye is looking and where the hand is located. (Photo: Hiroo Iwata)



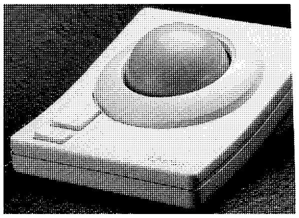
CyberForce Exoskeleton from Immersion

A commercial product that provides whole hand force feedback. In one sense, this is a class of glove. In the other, it is a specialized armature class device, which supports both input, like the other armatures which we have seen, and output, in the form of force feedback.

The armature becomes, in effect, a *display.* It is just a force, or *haptic* display, rather than visual. Nevertheless, this type of display requires rendering, just like a graphics display.

	*Fluid Reality* high-resolution dynamic fingerpad arrays Small (20 haptic pixels/cm) tactile finger-tip arrays which can be fitted inside the fingers of a glove to support the sensing of contact, shape, texture, etc. Shen, Ray-Grant, Mullenbach, Harison & Shultz (2023).

Additional Devices



Trackball (Abaton): can provide 2-D of information (relative) by rolling. Some trackballs can provide one more dimension by twisting. If this third dimension is provided, the device is a 2+1 D device, rather than 3-D, since all 3 dimensions cannot be controlled at once. Placement of the buttons is important: is the ball moved with the fingers and buttons by the thumb, or vice versa? This can have a significant effect on the ease of dragging, for example. Three DOF trackballs were used as early as 1964 at Lincoln Lab (Ball et al, 1966).

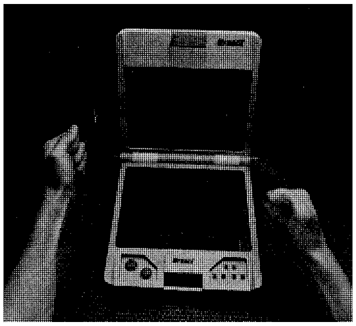
This is the ultimate “ballpoint pen.” It is a mouse mounted in a stylus-like package. (Fellowes)

***Isopoint* Roller Cursor Control from Alps Elect**

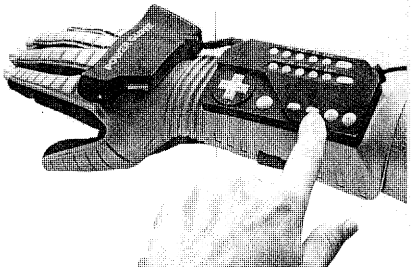
The *Isopoint* was a roller used for a while in the late 1980’s. It was mounted in the chassis just in front of the keyboard. It was accessible by the thumb. Rolling caused the cursor to move up and down. Sliding the roller caused it to move left and right. While not appropriate for drawing, the device was intended for text editingespecially with portable computers. It was used, for example, on the GRiDCase 1550sx portable. We are not aware of any comparative studies testing the device. (Photo: Alps Electric).

Do Game Controllers Point to the Future?

see also Strommen, E., Razavi, S. & Medoff, L. (1992).re desing and use of Nntendo controller.



Proximity sensor from Broderbund (Doherty (1989). This inexpensive controller ($69) senses position, direction and motion of the hands without any physical contact.



The *Powerglove* by Mattel. Provides X, Y & Z information, plus roll and amount of flex of fingers. The device can be interfaced to a personal computer, thereby giving a handle to virtual reality for about $89.00!

see Sturman, D.J. & Zeltzer, D. (1994). for a survey of glove-based input

Problems of Interfacing

Our current understanding is such that we are hard pressed to use the haptic channel to its full potential. We need more experience before this situation can be altered. However, obtaining this experience turns out to be rather difficult. If, for example, we want to gain some insights by comparing two devices, we will most likely find that they are incompatible physically, electronically, and/or logically. Hence, what should be a simple comparison turns into a logistical nightmare. Let us work through an example.

Suppose that we wanted to compare two tablets. To make things simple, let us assume that both communicate to the host computer *via* an RS-232 interface. The first thing that you might find is that despite the RS-232 "standard," one device has a 25-pin connector, the other has a miniature "telephone jack" connector , and the computer (an Apple Macintosh) has a 9-pin connector. We obviously have a problem. But let us assume that all three devices have a 25-pin connector. Then, the chances are that one is female and the other male. So much for "standard" physical compatibility.

Now if we do actually get both tablets connected to the computer, the next thing that we might find is that there is an electrical incompatibility. Namely, we will possibly find that one device requires a powered RS-232 and the other doesn't. Some computers that use RS-232 supply power, others don't. Again, we have a problem.

But let us assume that both devices connect physically and electrically (we won't even mention the possibility of the "null modem" problem). What we may find now is that one device communicates by request while the other must be polled, or generates interrupts. Since each of these styles of I/O can affect the design of the underlying application software, exchanging one device for the other may involve non-trivial software modifications.

For the sake of simplicity, let us assume that both devices function by interrupt-driven I/O and the application software is set up for this. What we will find next is that one encodes its data in binary-coded decimal (BCD) while the other transmits in binary digits. The number of bytes in each will differ, not to mention the fact that the data for the puck buttons will come in a different format for each device.

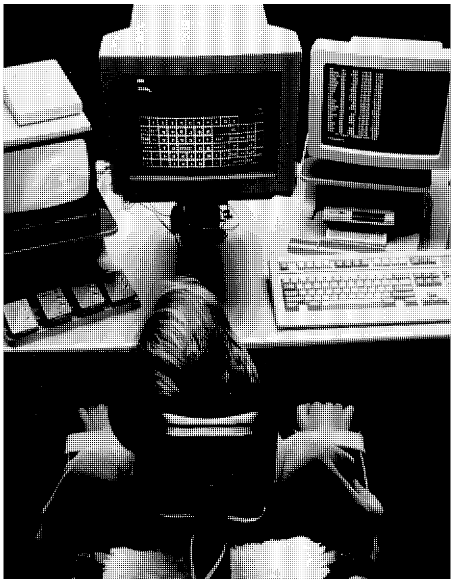
The point of this convoluted example is to emphasize how hard it can be to compare two similar devices that communicate using a "standard" interface. If the problems in this "simple" case are this involved, then what will happen in the likely case where we want to compare devices that differ even more greatly? The lesson to be learned here is that the path of least resistance will bias you *against* investigating designs that utilize alternative input techniques. The only way to counteract this bias is to take clear and definite measures in the R & D environment to set up appropriate structures and equipment that provide a proper test-bed for such comparative studies. This is simply far too uncommon in today's R & D environment, and is something that must be changed if we are to make substantive progress in this aspect of user interface design.

Transparent Access and the Physically Challenged

For most users, the problems of connecting different input devices to a system, as outlined in the previous section, are an annoyance. However, for users with physical disabilities, these problems can make the difference between their being able to use a computer or not. This, in turn, can have a major impact on their quality of life.

For most common input devices there exist special-purpose transducers that permit people with different physical disabilities to supply comparable signals. A mouse may be replaced by a tongue-activated joystick, or a button replaced by a blow-suck tube. It is reasonable to expect disabled persons to acquire such special-purpose devices. However, it is economically unreasonable and socially unacceptable to expect them to be dependent upon custom applications in order to interact with their systems.

What is required is *transparent access* to standard applications. That is, existing applications should be able to be used by simply plugging in the specialized replacement transducer. The difficulties in providing transparent access are exactly the same difficulties that we encountered in the preceding section where we wanted to replace one input device with another for comparative purposes. In recognizing that this is a problem "handicapping" all of us, perhaps the achievement of generalized transparent access will become a greater priority than it has up to now. It is a serious problem and needs to be addressed.



Input using non-intrusive eye-tracking.