

Communications Research Centre

A REVIEW OF HARDWARE INPUT DEVICES FOR INTERACTIVE GRAPHICS

by

W. SAWCHUK

IC

CRC TECHNICAL NOTE NO. 683



Department of
Communications

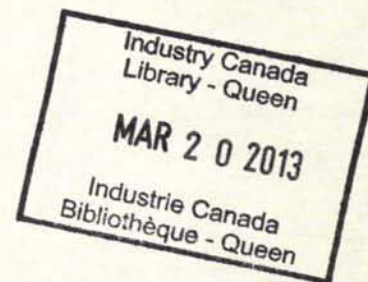
Ministère des
Communications

LKC
TK
5102.5
.R48e
#683
c.2
c.6

OTTAWA, DECEMBER 1976

COMMUNICATIONS RESEARCH CENTRE

DEPARTMENT OF COMMUNICATIONS
CANADA

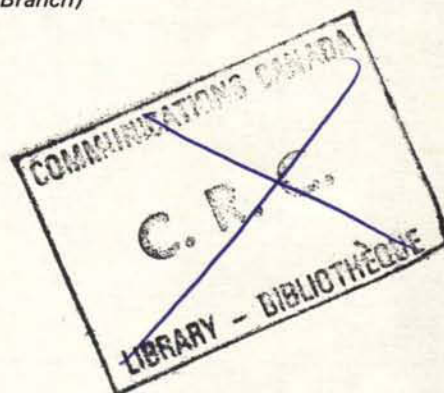


A REVIEW OF HARDWARE INPUT DEVICES FOR INTERACTIVE GRAPHICS

by

W. Sawchuk

(Technology and Systems Branch)



CRC TECHNICAL NOTE NO. 683

December 1976

OTTAWA

CAUTION

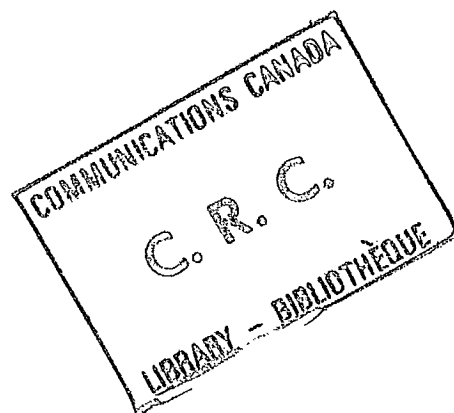
This information is furnished with the express understanding that:
Proprietary and patent rights will be protected.

AD 4283885
DL 5368231

TK
5102.5
R482
#683
C. b

TABLE OF CONTENTS

ABSTRACT	1
1. INTRODUCTION	1
2. GRAPHICAL INPUT FUNCTIONS	2
3. HARDWARE INPUT DEVICES	3
3.1 Keyboards/Buttons	3
3.2 Potentiometric Devices	4
3.2.1 Joystick	4
3.2.2 Trackball	5
3.2.3 Grafacon	5
3.2.4 Mouse	5
3.2.5 Knee Control	5
3.3 Light Pens	5
3.4 Tablets	5
3.4.1 RAND Tablet (Encoded Wire Matrix)	7
3.4.2 Voltage Gradient Technique	7
3.4.3 High Frequency Phase-Sensing Tablet	7
3.4.4 Acoustic Ranging Tablet	7
3.4.5 Magnetostrictive Ranging Tablet	7
3.4.6 Tough-Sensitive Tablet	9
3.4.7 Electromechanical (Digitizers)	9
3.4.8 Operational Requirements	10
3.4.8.1 Modes of Operation	10
3.4.8.2 Performance Criteria	10
3.5 Valuators	10
3.6 Device Cost	11
4. RESULTS OF PREVIOUS DEVICE EVALUATION	11
5. CONCLUSIONS	12
6. REFERENCES	13



A REVIEW OF HARDWARE INPUT DEVICES FOR INTERACTIVE GRAPHICS

by

W. Sawchuk

ABSTRACT

This review presents a classification of the input functions for an interactive graphics system and describes the various types of hardware devices suitable for fulfilling these functions. Emphasis is on commercially available hardware such as potentiometric devices, light pens and tablets. The published results of experiments on device evaluation and performance are summarized, and the need for further more comprehensive evaluation is discussed.

1. INTRODUCTION

A user can interact with a computer-generated graphics display by the use of a variety of hardware devices. These devices may include one or more elements such as *light pens, tablets, keyboards, joysticks* or *trackballs*. Other types of hardware devices have been designed but these have been developed to fulfill a specific requirement or conform to a specific system configuration; generally, they are not readily available on the market. Although only hardware input devices are considered in this review, other techniques, such as voice input to the computer, have potential. Research using voice input for interactive graphics has been directed to replacing the manual selection of screen-displayed commands (Neroth, 1975), thus alleviating the need for the user to be in direct contact with or close to the display screen.

A hardware device can perform one or more graphical input functions although certain devices may be more suitable than others. The traditional device for computer input is the alphanumeric keyboard, but in a graphics system it has limitations in fulfilling a graphical function such as locating items on a screen. A program can be written to have a screen marker moved by certain keys of the keyboard but the interaction would be awkward. Although a number of different input devices may fulfill a particular function, their performance, or the ease with which they accomplish the task, is not equivalent. Also, situations may arise where the best hardware device for a particular function cannot be utilized because of physical constraints to a system. For example, a light pen is considered to be an ideal selector of displayed screen items when the user is situated in front of the screen, however, the selection of items would be difficult if the user did not have direct access to the screen.

There are very few studies which evaluate the relative merits of hardware input devices and user reactions to them. Further and more complete comparisons are necessary, particularly from the human factors point of view. At present, it is difficult to specify which device is the most suitable for a particular graphical function or application.

This Technical Note summarizes the hardware devices that can be used for providing input to an interactive graphics system. It is believed that this review is a reasonably complete summary of the devices available. The published results of device performance and evaluation are also discussed, however any comments that have been made are personal assessments rather than conclusions drawn from independent comparisons or evaluations.

2. GRAPHICAL INPUT FUNCTIONS

The computer programmer for an interactive graphics system can program interactions in a variety of ways and can make use of a number of different hardware devices to accomplish these interactions. But whatever the device chosen there are only a number of basic modes of interaction. The ability to identify or classify the mode of interaction between an input device and a computer graphics system provides the flexibility of interchanging one hardware device for another, and enables the transportability of graphics programs among installations that may have different devices. These qualities lend to a system the basic concept of device independence.

The modes of graphical input can be classified as (1) general input functions that could also be associated with a non-graphical computer system, and (2) functions specifically related to graphics. Each class can be further subdivided into three distinct functions (O'Brien, 1975).

For the general input functions the subdivisions are:

1. Textual string input. Each input character has an associated character code.
2. Input an action from a selection of commands specified by an application program. Switches or pushbuttons may be used with the distinction that the former have a hardware flag, whereas, the latter have a software flag associated with them.
3. Numeric value input. The input of a number to the system in a direct manner so that there is no need for syntax checking. Input can be made by a continuous device, such as a potentiometer, called a valuator.

The three functions specifically associated with a graphics system are:

1. To identify, which is the selecting or "picking" of specific items displayed on the screen. The light pen is an excellent hardware device for this function although other devices, such as a *tablet*, *joystick*, *trackball*, etc., in conjunction with software techniques, can also be used. By its physical position the light pen provides immediate feedback to the user that an item has been selected, whereas other devices require a software controlled marker or cursor for visual feedback.
2. To position, which is the directing or "locating" of a controllable screen marker to specific screen coordinates. The marker may be controlled by the hardware device in a relative manner or it may be under program control. The marker may also be constrained to move only in a specified direction. As well as positioning a screen marker, this function or a similar one can be designed to move the origin of the total screen image to another coordinate location. A somewhat different function could be programmed to provide a zoom capability.

3. To sketch, which is the monitoring of the location in terms of screen coordinates of a display marker, or a drawing stylus such as that of a tablet; sketching can also be considered as the accumulation of position locations. The coordinate locations are plotted either on a point-by-point basis, where the stylus touches only specific points, or in a continuous manner where points differ by only an incremental amount. Some visual feedback is usually provided on the screen in the form of a continuous smooth curve, or straight lines joining the specified points. The start and the end of the sketching function can be indicated by activating a switch on the stylus.

For each of the above six functions a virtual device can be designated. This relationship is summarized as follows:

Function	Virtual Device	Input Device
input of text string	keyboard	button (or key)
input of action command	pushbutton	
input of numeric value	valuator	valuator
identification/selection	picker	picker
position	locator	locator
sketch	digitizer	

However, a hardware device particularly suited to one function may perform one or more of the other functions with varying capability. Thus, Foley and Wallace (1974) have suggested that the number of virtual devices can be reduced to four by combining the keyboard and pushbutton into one group, and by having the position and sketch functions performed by the locator device. Each virtual input device would have an associated hardware device.

The four classes of input devices are listed in Table 1, and for each category some of the hardware devices are indicated. Note that nearly all of the hardware devices, when aided by software, can be placed in the role of each of the virtual ones. For example, a picker can be simulated by a stylus on a tablet surface where the stylus movement is coordinated with that of a screen displayed marker. The stylus can direct the marker onto a particular displayed item and that item can be "picked" by activating the stylus switch.

3. HARDWARE INPUT DEVICES

There are a number of different types of hardware input devices, each one designed initially to fulfill a particular graphical function. The common types can be grouped as *keyboard arrangements*, *potentiometric devices*, *light pens* or *tablets*. For some types, a diversity of designs, based on different electrical-mechanical techniques, have been developed. Descriptions of the hardware devices that are available are presented in the following sections.

3.1 KEYBOARDS/BUTTONS

The familiar alphanumeric keyboards of standard typewriters are the main class of buttons or keys. These are used mainly for input of text. In addition, there are the multiple or chord keyset (Engelbart, 1973), keyboards that input numerics only, and special function keyboards such as one that contains four cursor control buttons. Also included in this group are programmed function buttons such as various pushbuttons, toggle switches and depressable bars, and simulated keyboards or light buttons on the display screen. However, this latter group requires a picker such as a light pen or a marker moved by a locator to perform the selection. Switches on light pens, tablets and alike are also classed as buttons and can perform the select function.

TABLE 1
Classification of Graphical Input Devices

Picker		Locator		Button		Valuator	
light pen		tablet		keyboard	[programmed function keys]	potentiometer	
tablet	[with screen marker]	joystick				tablet	[single axis movement to input value]
joystick		trackball		keyboard	[alphanumeric keys]	joystick	
trackball		mouse				trackball	
mouse						mouse	
keyboard	[propel marker]	light pen	[with screen marker]	light pen	[switch signifies that indicated entity to be entered or action performed]	light pen	[manipulate dials and scales on screen]
keyboard	[numeric or alphanumeric to select names attached to items to be picked]			tablet			
		keyboard	[4 keys specifying marker movement: up, down, left, right]	joystick		keyboard	[numeric keys form digit string]
				mouse			
				light button	[selected using picker]		
						light button	[number selected by using picker to form digit string]

3.2 POTENTIOMETRIC DEVICES

Another group of hardware devices is one that is based on the arrangement of two potentiometers. Each potentiometer provides positioning information for one coordinate of the screen. A separate switch on the device is usually provided for making a coordinate selection once a display marker is correctly positioned.

3.2.1 Joystick

The joystick (Figure 1) has been used for a number of years by radar operators and air traffic controllers. Its operation is based on two potentiometers mounted perpendicularly and coupled to a vertical control shaft in such a way that shaft motion is resolved into two orthogonal coordinates. Variation in the construction of the joystick includes one that returns the control handle to center once it is released. In this type of joystick the amount of displacement of the handle from its center position can control the rate of motion of the screen marker, that is, the greater the handle displacement, the faster a marker will move in a particular direction. This is unlike most other potentiometric devices which can logically only control position. Some joysticks have a stiff or isometric control handle where there is no handle motion but screen marker displacement is related to the force exerted on the handle.

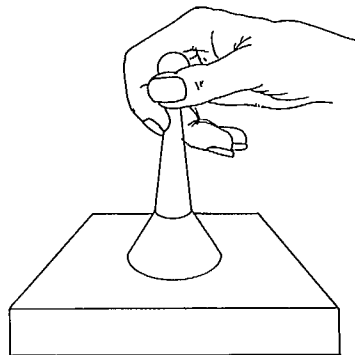


Figure 1. Joystick

3.2.2 Trackball

This device (Figure 2) is a displacement control similar to the joystick except that rotation of a ball, rather than movement of a control handle, determines the coordinate positions.

3.2.3 Grafacon

One example of the variation on the arrangement of two potentiometers is the Grafacon (Figure 3) which was originally designed for curve tracing. It consists of an extensible arm connected to a linear potentiometer with the housing pivoted on an angular potentiometer. This polar coordinate arrangement can then be interpreted in terms of a rectangular coordinate system.

3.2.4 Mouse

This device (Figure 4), developed by the Stanford Research Institute (English et al, 1967), consists of a small plastic box resting on two orthogonally mounted metal wheels and a third pivot point. Each wheel has a potentiometer attached to its shaft and as the wheels ride on a surface the combined rotating and sliding movement can be translated into displacements in the two orthogonal coordinates. Mounted on top of the box are three pushbuttons; they may be programmed for options such as coordinate select, constrain marker movement to one of the orthogonal coordinates, etc.

3.2.5 Knee Control

To free the hands for other activities, devices have been designed which can be operated by the lower limbs. One example is the knee control by English et al (1967). It consists of two potentiometers, a knee lever and associated linkages. The linkage is spring loaded in one side direction and gravity loaded downward so that side-to-side motion of the knee is translated into horizontal displacement on the display while up-and-down knee motion causes vertical displacement.

3.3 LIGHT PENS

The light pen is a device which may be used directly on the screen surface. It is handheld and pointed at the screen to identify a specific location as an electron beam sweeps past that point (Figure 5). The main elements of a light pen are a photodetector and an optical arrangement that focuses the light within the field of view. These elements are enclosed within a pen-shaped housing which may also include an amplifier to increase the detector signal. Some units may also have a "finder circle" of light which enables the user to discern readily the region that is within the detector's field of view. Most light pens have a finger-operated switch or shutter on the housing to allow the light to reach the detector.

The usual detectors are small transistor-types, such as photodiodes, with a response time typically in the range of 0.3 to 5 microseconds. These are more suited for slower displays. For faster response, a highly sensitive detector such as a photomultiplier tube can be used. Since this detector is too bulky to be mounted in a handheld configuration, a fiber optic pipe can be used to direct the light from the pen to a box that houses the detector and associated electronics. Because photosensitive devices are generally designed to be more sensitive in one region of the optical spectrum, there is difficulty in using such devices over the complete color range available with color displays.

3.4 TABLETS

A tablet is a flat surface device, ten inches square or greater, on which the user draws with a stylus, a pen-shaped device. The tablet surface is usually of a conductive material that couples coded electronic signals to the stylus. The stylus sends these signals to the decoding electronics. In some cases a sensitive amplifier is built inside the stylus to amplify the coded signals.

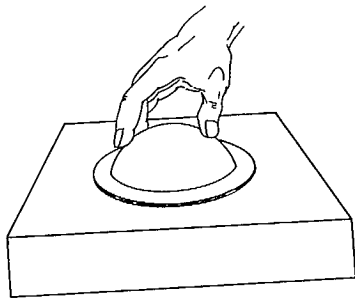


Figure 2. Trackball

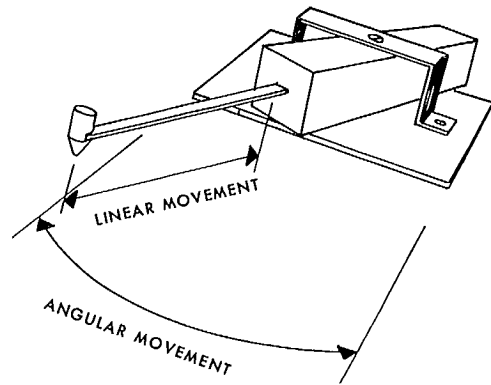


Figure 3. Grafacon

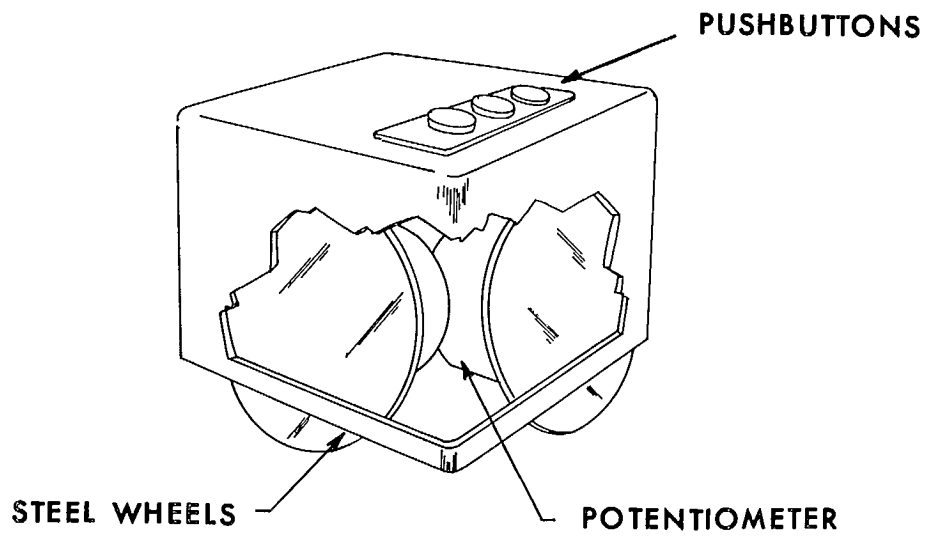


Figure 4. Mouse

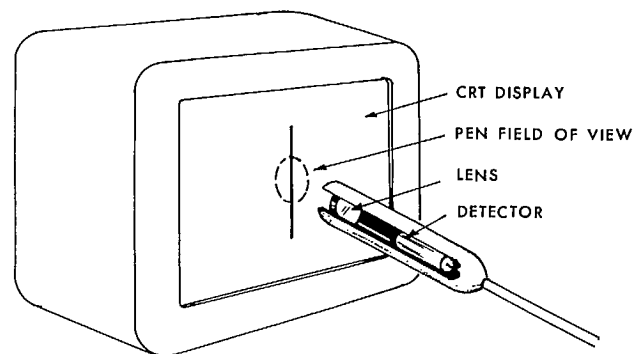


Figure 5. Light Pen

The tablet makes a convenient locator, particularly when combined with a screen displayed marker. It is also widely used as a digitizer, although in some tablet designs the linearity may be distorted by the user if care is not taken during the digitizing process.

3.4.1 RAND Tablet (Encoded Wire Matrix)

In this type of tablet, the RAND tablet (Davis and Ellis, 1964), the surface has embedded in it orthogonal sets of wires spaced very closely together, e.g., 100 per inch, and each wire carries a unique digitally coded signal (Figure 6). A high impedance stylus detector, through capacitive (sometimes referred to as electrostatic) coupling, picks up the coded signals from those wires that are closest to it. Capacitive coupling between tablet and stylus permits the tracing of paper sheets. The detected pulse sequence provides a unique representation for each position on the tablet and can be converted easily to a binary representation. A small switch near the stylus tip signals whether or not the stylus is ready to input information.

The RAND tablet is one of the most accurate and linear of this class of input devices. Its drawbacks are complexity and high cost, and that the stylus is susceptible to wear.

3.4.2 Voltage Gradient Technique

This technique uses voltage gradients set up in a sheet of partially conductive material as a tablet surface (Turner and Ritchie, 1970), (Figure 7). Alternate horizontal and vertical potentials are applied across the sheet, and the stylus, when in contact with the sheet, senses a potential corresponding to its position. To be linear, such a tablet requires a surface material of uniform resistivity. The material must have a high enough resistivity across which a reasonable potential can be developed, and yet be able to withstand the wear of constant contact of the moving stylus.

3.4.3 High Frequency Phase-Sensing Tablet

A modification of the voltage gradient tablet is one that uses two high frequency alternating currents, one for horizontal and one for the vertical coordinate. The phase of these signals varies with location on the tablet. The signal received by the stylus can be detected, filtered and related to the stylus coordinates.

This method enables the use of relatively low quality conducting sheets and any non-linearity in the tablet can be compensated by resistors connected to the contacts at each edge. To achieve a precision of one percent only seven contacts are used in a Sylvania tablet (Teixeria and Sallen, 1968). Since high frequency signals are used, the stylus need not be in contact with the surface. The magnitude of the signal can be used for height information.

3.4.4 Acoustic Ranging Tablet

A tablet that operates on an acoustic principle (Brenner and deBruyne, 1970) has been designed by Science Accessories Corporation. It uses two strip microphones mounted along orthogonal sides of the tablet (Figure 8). The sound pulse from a spark generated at regular intervals from the stylus tip is picked up by the microphones. Delay between spark creation and sound detection is measured and translated into tablet coordinates. Coordinates are provided even when the stylus is off the surface although they will be inaccurate. However, three dimensional coordinates could be provided by an additional set of microphones along the other two sides of the tablet and a second pair of detectors. A difficulty with any sound generating system such as this acoustic tablet is the effect of ambient noise interference. Another problem with sound generating systems is the annoyance to the operator caused by the buzzing stylus.

3.4.5 Magnetostrictive Ranging Tablet

Another ingenious method of tablet design, in a manner similar to the RAND tablet, uses wires with magnetostrictive properties. Stress that results from current flowing in the magnetostrictive material causes an

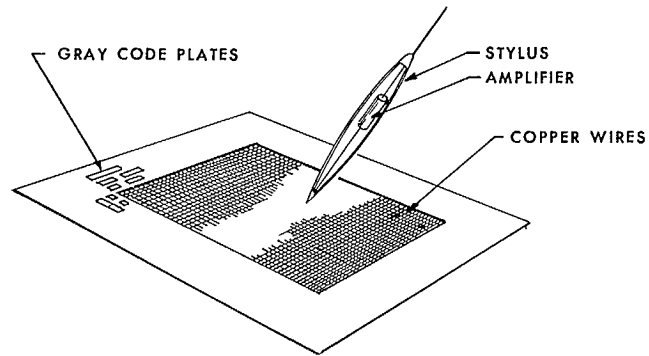


Figure 6. RAND Tablet

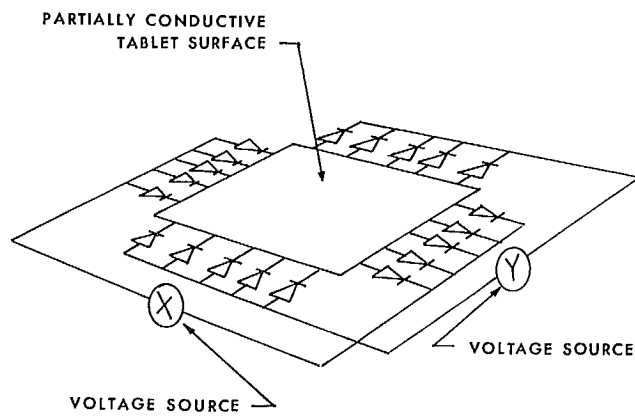


Figure 7. Voltage Gradient Tablet

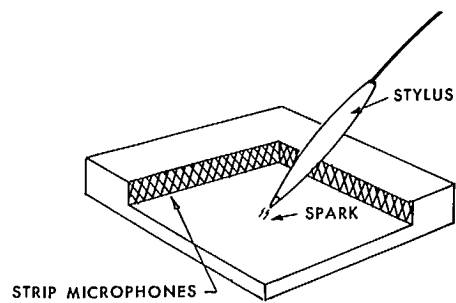


Figure 8. Acoustic Tablet

acoustic wave to be propagated along the wire. When a stylus is moved on or near the tablet a pick-up coil in the stylus tip can detect the magnetic field changes caused by the acoustic wave. The time interval between sending and receiving the pulses for both coordinates is sufficient to identify every point in the grid. Summagraphics Corp. has designed a tablet using this principle.

3.4.6 Tough-Sensitive Tablet

A unique tablet that has no active components embedded in the glass surface and which can use a non-active probe, such as a pencil, finger, etc., has been developed by the National Research Council of Canada (Hlady, 1971) and is marketed by Instronics Ltd. It can be mounted directly onto the screen of a display unit. This tablet operates on a pulse echo-ranging principle using high frequency elastic surface waves (Figure 9). Each of two sides of the tablet has 36 transducers alternately connected to a transmit and receive circuit. The position of any object is determined by the time lapse between transmission and reception of a reflected 4 MHz pulse modulated elastic surface wave. The sensitivity of the tablet is aided by moisture so that a finger or a felt-tipped pen makes a better probe than a lead pencil. Sharp or pointed objects are generally poor and a dirty surface can disrupt the surface waves.

A somewhat similar touch sensitive device for use with CRT displays has been developed by Marconi in England. This system uses a number of discrete wires (typically 32) terminated on a clear plastic panel. When a particular wire is touched, the body capacitance is sensed and related to position. Another device of this type that can also be placed in front of a CRT is from Control Data Corp., and it consists of a row of 20 translucent strips which are sensitive to finger contact.

A different type of touch sensitive device for mounting on a display system has also been produced by Marconi. It is called "Digilux". Rather than relying on discrete wires, it is based on the use of two orthogonal sets of narrow, infrared light beams which form an invisible grid over the display screen. The beams can be interrupted by a finger pointing at the screen, and the location of the finger is passed on to the controlling computer.

3.4.7 Electromechanical (Digitizers)

Devices of this class generally are of larger dimensions than those described above. They are more specialized and generally are used for digitizing graphs, charts, etc. for processing rather than as locators. Of course, within the constraint of their accuracy, the tablets described above can also be used for digitizing. The electromechanical devices will be described very briefly for completeness of this report.

The two main components of a typical digitizer are the table to hold a document and a cursor for tracing. Below the table is an electrical coil generating a signal that is sensed by the cursor. The cursor contains a sensing coil and as it is moved servomotors cause the generating coil to follow the cursor's motion in both the x and y coordinate directions. Encoders provide the coordinate values to the circuitry.

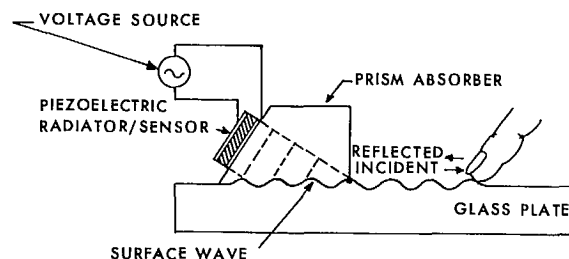


Figure 9. Surface Wave Pulse Ranging

3.4.8 Operational Requirements

Because there are a variety of tablet designs and a diversity of working surfaces, a fair comparison of a design can only be made on the basis of their operational and performance parameters. Of course, there may be physical attributes to each design that may be more suitable to a particular user or situation.

3.4.8.1 Modes of Operation

Tablet operational modes generally include some or all of the following:

- *Single shot:* When the stylus touches the tablet, or a switch is actuated, a coordinate pair is input to the computer.
- *Continuous running:* Coordinate pairs are generated at the maximum rate. This may depend on whether the stylus is near (near-free run); in contact with the tablet surface (contact-free run); or whether a switch is activated (switch-free run).
- *Programmed remote control:* Computer commands new coordinate pairs.
- *Incremental:* A coordinate pair is generated whenever the stylus has moved a specified distance. In addition, some tablets will generate data only when the stylus is moved.

3.4.8.2 Performance Criteria

The performance of a tablet can be assessed according to resolution, precision, and data rate, as well as other parameters.

Resolution is the smallest coordinate unit that can be separately located on the coordinate grid. If each axis of a 10 inch display has 1024 addressable locations then the resolution is $10/1023 = .0098$ in.

Precision (or accuracy or linearity) is a measure of the linearity of the addressable grid locations, that is, the difference between the actual point location to the ideal location. For example, for the above 10-inch display a point at x should ideally be $x(10)/1023$ inches away from the $x = 0$ line.

Data rate is the number of pairs of coordinate points (x and y coordinates counted as one pair) that can be transmitted per unit time.

3.5 VALUATORS

Numeric values unrelated to the drawing space can be entered into a graphics system by the use of a device called a valuator. For example, a potentiometer can be used directly as a low resolution valuator. One arrangement to input numeric values without special hardware devices is to display on the screen one of a variety of dials and scales, and then use a light pen or a locator to manipulate it in various ways. An interesting technique of this nature is the Newman (1968) "light handle". This particular software technique presents on the display screen for the user a cross within a square. Rotation of the cross in either direction will cause an increase or decrease in the displayed numeric value. The rate at which the value changes can be altered by moving the horizontal position of the center of rotation to the right or left of the square.

The usefulness of any technique can be increased if the current numeric value is also displayed on the screen. The limited resolution and accuracy of valuator can be improved by a logarithmic scale or by having the output value changed at a rate proportional to the square or exponential of the tracking device velocity. A useful approach for potentiometers is to have the output value dependent on the rate of change: fast rotations to indicate a rapidly increasing number, and slower rotations to signify a smaller increase. Rotation in an opposite direction would specify a decreasing value.

3.6 DEVICE COST

The cost of graphic tablets is variable depending on the size, construction and associated hardware. The basic price of a tablet can range from approximately \$1000 to \$8000, but for the common 11 x 11 inch (28 x 28 cm) size a \$3000 unit price is typical.

Joysticks and trackballs also vary in price over a wide range. The price depends on type, quality and options, and can range from a few hundred dollars to ~\$2000.

Devices such as lightpens are priced from ~\$300 to \$1000; the mouse at ~\$400. Valuator, the Grafacon, knee controls and other such devices are not available on the general market so no realistic prices can be quoted.

4. RESULTS OF PREVIOUS DEVICE EVALUATION

Although numerous graphical input devices have been used over the past number of years few studies have evaluated the performance and compared individual devices that fulfill a particular function. Those studies that have been carried out are far from complete and have deficiencies in many respects. A main shortcoming has been a thorough evaluation of a device from the human factors point of view.

English et al (1967) at the Stanford Research Institute have carried out experimental studies on the use of various potentiometric devices (mouse, joystick, Grafacon, knee control) and the light pen as selection devices of characters and words on the display screen. The displayed screen targets were arrays of x's and the marker was a plus sign. These experiments were carried out to obtain data on the time it took to move the limb to the device, time to move the marker to the desired position, the ease of use and the error rate. A group of eight experienced and three inexperienced persons was used.

The Stanford group suggests that the mouse, knee control and light pen are faster and more accurate than the other devices, however, their experiments involved a small number of people and the experienced group may have had a biased familiarity with the mouse. The inexperienced individuals had less difficulty with the light pen and knee control. This latter device was not included in the tests involving experienced users. All found the light pen, as a pointing instrument, natural to use although many found it fatiguing after prolonged use. The mouse seemed to be accurate and non-fatiguing but did require some practice in its use. The joystick and Grafacon tended to overshoot the target; pressing the select switches on these devices caused marker movement and an incorrect fix. The knee control took no limb movement time, freed both hands for other activities and ranked high in both speed and accuracy.

English et al conclude from their experiments that the advantage of a particular device will depend greatly on the system with which it will be used, and the reaction of the system to the display selections. They state that appeal to inexperienced users should not be the basis of judging devices, however, in the application of interactive graphic displays to communications it is the person without intimate knowledge of graphics systems who may be the main user.

In further elaboration of the above tests Engelbart (1973) reemphasizes the advantages of the mouse as a device for selecting items on a display screen. He does conclude that its advantages seemed to be based on factors such as convenience and "feel". Engelbart also proposes that in certain requirements a chord keyset device may be a better device for text entry than a keyboard because it requires only one hand and the user's eyes never need to leave the display screen in order to access and use the keyset. He does concede, however, that a chord keyset would not be as fast as a keyboard for continuous text entry and that practice would be required to learn the keyset letter code. Engelbart speculates on the use of the chord device for screen selection of light buttons by having an alphabetic tag on each entry; one stroke of the keyset would perform the screen selection action.

A comparison of joystick and trackball devices in their ability to position a marker on a target was carried out by Mehr and Mehr (1972). Four experienced and 20 inexperienced persons were used. No practice was allowed and typical learning curves indicate that after 4 to 5 runs there is little improvement in decreasing the positioning time. The trackball and isometric joystick indicate a shorter time than spring-centered or remain-in-position displacement joysticks. Test results of "time to position" varied from 2.5 to 4 sec for screen displacements of 300 steps to 2.9 to 4.8 sec for displacements of 900 steps. The minimum "time to position" was achieved by a trackball with the finger-operated isometric joystick about the same. The two types of displacement joysticks were somewhat higher. Increased trackball friction would increase the time to position and thus make the isometric joystick a more responsive control. The authors suggest that these conclusions be treated with caution since factors such as size, reliability and sensitivity also are involved; also the results will be biased to those devices for which the tests are optimized. Their report does not include comments on the devices by the individuals who participated in the evaluation.

In a study of the light pen from the human factors point of view Barmack and Sinaiko (1966) conclude that:

1. It does not feel "natural" like a real pen or pencil;
2. it lacks precision because of its aperture, distance from the display screen and parallax;
3. its use with the common vertical CRT leads to fatigue;
4. it is too slow;
5. it may require "inking" up;
6. contact with the computer may be lost unintentionally;
7. frequent required simultaneous button depression can cause slippage and inaccuracy;
8. attachment by a cable is inconvenient.

On the positive side, Barmack and Sinaiko found that, in comparison to other graphical input devices, the light pen can give direct positional information without further scanning, and it requires less formidable programming. These authors suggest there is little difference in any one potentiometric device over another.

5. CONCLUSIONS

There is a need for further and more detailed intercomparison of graphic input devices particularly when there is a requirement to choose an arrangement that will be most advantageous for the user and minimize the amount of his adaptation or training. Ideally, one would like to consider each of the devices available and evaluate its ability to perform each one of the six graphic input functions. However, practical considerations of interfacing and software support may preclude such a complete effort. In certain instances it may not require much formal experimentation to conclude that a particular device would be unsuitable to perform a particular function.

Some of the factors that should be considered in an evaluation experiment are:

- Learning time of the user;
- the time to move the hand from one device to another if more than one is to be used;

- selection time, i.e., the time to move the device from its initial position to a final position when the action has been completed. For example, in an editing sequence the time to (1) position a marker at a designated character on the screen, or (2) select a word on the screen;
- number of attempts made to select a particular item on the screen;
- fatigue measured by increase in error rate;
- comments by both experienced and inexperienced users as to the suitability or deficiency of various devices to perform various functions;
- constraints on device use by right or left-handed individuals;
- device capability in the context of a particular graphics application.

In any evaluation, or for that matter, any graphics work, attention must be given to the environment surrounding the display system and its effect on the user. Such human factors as a properly arranged work surface, comfortable chair, noise and light levels, accessibility to input devices, and interchangeability for right and left-handed persons may have a bearing on the outcome of device evaluation. In addition, human-factors must be weighed and evaluated according to system use by occasional users as compared to regular heavy users.

Another important consideration in an evaluation is the supporting software and control hardware that interface a device to the graphics system. Factors such as availability, reliability, cost and responsiveness may have a critical bearing on the way the system relates to a given device, and ultimately, the user.

Although many diverse factors can effect an interactive system, the prime consideration is how well an input device in the hands of a user performs a given function.

6. REFERENCES

- Barmack, J.E. and Sinaiko, H.W., 1966, *Human Factors in Computer-Generated Graphic Displays*. Institute for Defense Analyses, Arlington, Va. Study 234, April (AD636 170).
- Brenner, A.E. and deBruyne, P., 1970, *A Sonic Pen: A Digital Stylus System*. IEEE Trans. Electron. Comput., EC-19, 546.
- Davis, M.R. and Ellis, T.O., 1964, *The Rand Tablet: A Man-Machine Graphical Communication Device*. FJCC 1964, Spartan Books, Baltimore, Md., 325.
- Engelbart, D.C., 1973, *Design Considerations for Knowledge Workshop Terminals*. AFIPS Conf. Proc., 42, 221.
- English, W.K., Engelbart, D.C. and Berman, M.K., 1967, *Display-Selection Techniques for Text Manipulation*. IEEE Trans. on Human Factors in Electron., HFE-8, 5.
- Foley, J.D. and Wallace, V.I., 1974, *The Art of Natural Graphic Man-Machine Conversation*. Proc. of the IEEE, 62, 462.
- Hlady, A.M., 1971, *A Display Overlay for Computer Input*. Paper presented at the 2nd Man-Computer Communications Seminar, National Research Council of Canada, Ottawa, 31 May — 1 June.
- Mehr, M.H. and Mehr, E., 1972, *Manual Digital Positioning in 2 Axes; A Comparison of Joystick and Track Ball Controls*. Proc. of 16th Annual Meeting Human Factors Society, October.

- Neroth, C.C., 1975, *A Graphical Programming System With Speech Input*. Comput. and Graphics, 1, 227.
- Newman, W.M., 1968, *A Graphical Technique for Numerical Input*. Computer Journal, 11, 63.
- O'Brien, C.D., 1975, *IMAGE — A Language for the Interactive Manipulation of a Graphics Environment*. M.Eng. thesis, Carleton University, Ottawa.
- Teixeira, J.F. and Sallen, R.P., 1968, *The Sylvania Tablet: A New Approach to Graphic Data Input*. SJCC 1968, Thompson Books, Washington, D.C., 315.
- Turner, J.A. and Ritchie, G.J., 1970, *Linear Current Division in Resistive Areas: Its Application to Computer Graphics*. SJCC 1970, AFIPS Press, Montvale, N.J., 613.

CRC DOCUMENT CONTROL DATA

1. ORIGINATOR: Department of Communications/Communications Research Centre

2. DOCUMENT NO: CRC Technical Note No. 683

3. DOCUMENT DATE: December 1976

4. DOCUMENT TITLE: A Review of Hardware Input Devices for Interactive Graphics

5. AUTHOR(s): W. Sawchuk

6. KEYWORDS: (1) Input Devices
(2) Graphics
(3) Interactive

7. SUBJECT CATEGORY (FIELD & GROUP: COSATI)

09 Electronics and Electrical Engineering
09 02 Computers

8. ABSTRACT:

This review presents a classification of the input functions for an interactive graphics system and describes the various types of hardware devices suitable for fulfilling these functions. Emphasis is on commercially available hardware such as potentiometric devices, light pens and tablets. The published results of experiments on device evaluation and performance are summarized, and the need for further more comprehensive evaluation is discussed.

9. CITATION: _____

SAWCHUK, WILLIAM
--A review of hardware input devices
for interactive graphics.

LKC
TK5102.5 .R48e #683
c.2
A review of hardware input
devices for interactive
graphics

DATE DUE
DATE DE RETOUR[illegible]

LOWE-MARTIN No. 1137

CRC LIBRARY/BIBLIOTHEQUE CRC
TK5102.5 R48e #683 c. b

INDUSTRY CANADA / INDUSTRIE CANADA



212177



Government
of Canada

Gouvernement
du Canada