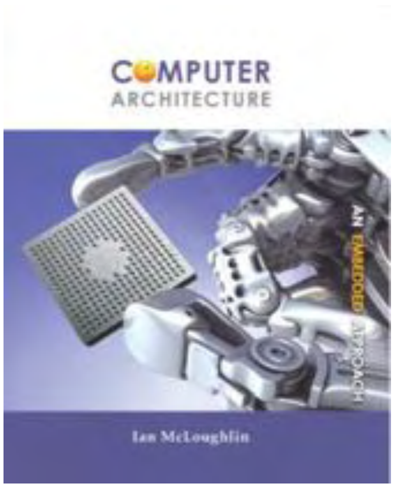
Computer Peripherals

School of Computer Engineering
Nanyang Technological University
Singapore

These notes are part of a 3rd year undergraduate course called "Computer Peripherals", taught at Nanyang Technological University School of Computer Engineering in Singapore, and developed by Associate Professor Kwoh Chee Keong. The course covered various topics relevant to modern computers (at that time), such as displays, buses, printers, keyboards, storage devices etc... The course is no longer running, but these notes have been provided courtesy of him although the material has been compiled from various sources and various people. I do not claim any copyright or ownership of this work; third parties downloading the material agree to not assert any copyright on the material. If you use this for any commercial purpose, I hope you would remember where you found it.

Further reading is suggested at the end of each chapter, however you are recommended to consider a much more modern alternative reference text as follows:



Computer Architecture: ***an embedded approach***
Ian McLoughlin
McGraw-Hill 2011

Chapter 5. Mouse and Tackball

5.1 History

The mouse was invented in 1965 at Stanford Research Institute by Douglas. The original mouse used a pair of wheels turning potentiometer shafts to encode X and Y motion into analog signals.

The mouse was redesigned at the Xerox Palo Alto Research Centre to use ball bearings as wheels, and optical shaft encoders to generate digital quadrature signals. The mouse was again redesigned to use a single large ball driving mechanical digital shaft encoders, thus eliminating the drag of side-slipping wheels.

Early mechanical mice were unreliable: the balls or wheels would get dirty and slip rather than roll or the commutators would get dirty and skip. All of the mechanical parts made the mice very expensive. The problems with mechanical mice led to the development of optical mice, which track motion without moving parts by optically imaging a special surface onto an optical detector within the mouse. MIT and Xerox had independently built completely different optical designs within days of each other some fifteen years after the original invention of the mouse.

An-acoustic mouse was invented after the optical mouse, but it was not a market success.

Mice are supplied on computers and workstations from Apollo, Apple, DEC, IBM, SUN Microsystems, Symbolics, Xerox, and many others. The largest mouse vendors are Alps Electric, Logitech, and Mouse Systems. The mouse has now become the universal Graphic User Interface (GUI) input device.

Mice are commonly rated by their resolution, typically stated as counts per inch (cpi) of travel. Most mice have a **resolution of 100 to 200 cpi**. The higher the resolution, the less motion is required to move the cursor a given distance, but the harder it is to position the mouse on an exact point. The resolution can be decreased by the software to make accurate positioning easier by dividing the count from the mouse.

Mice generally include **one to four push buttons** on the upper surface of the housing. A button is pushed to select the object pointed to, such as an item in a menu, or to mark a position, such as the start of a text block to be moved. Push buttons can also be used for other application-dependent functions.

5.2 Motion Sensing

Types of Motion. Mice sense their displacement and direction of motion across a work surface. This motion can be sensed in one of two ways: relative to the work surface or relative to the mouse.

Motion Relative to the Work Surface. When a mouse senses motion relative to a work surface, its output corresponds to its motion relative to the X and Y axes of the surface. The surface is usually printed with a regular pattern of lines or dots; sensing means within the mouse detect its motion over the patterned surface. The output is independent of the orientation or rotation of the mouse, within limits, and is related only to its motion over the work surface.

Motion Relative to the Mouse. When the mouse senses motion relative to itself, it does so independently of its orientation on the work surface. It can be moved in any direction, or rotated, and its output will correspond only to the motion relative to its own X and Y axes. Its orientation with respect to the work surface is unimportant

5.3 Mechanical Mice

Motion Tracking Methods. Mechanical mice use wheels or balls to convert their linear motion across a surface into the rotary motion of commutators or shaft encoders.

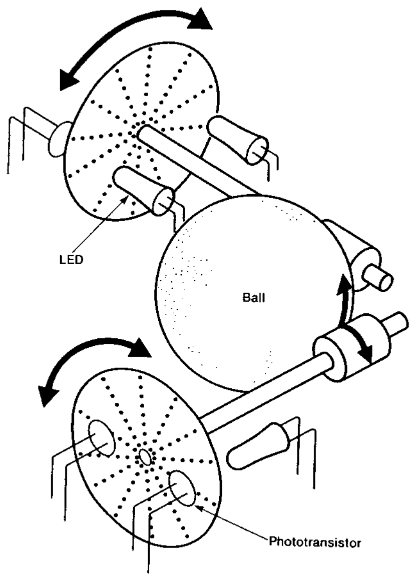


Figure 0-1 A Typical mechanical mouse with ball and shafts

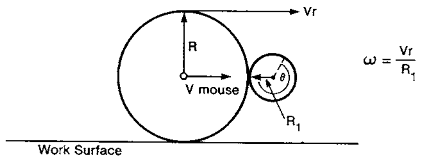


Figure 0-2 Ball and Shaft

Mice that use a ball for motion sensing can be represented by the system shown Figure 0-1 and Figure 0-2. The velocity of the circumference of the ball, Vr, is equal to the velocity of the mouse, V. Since the shaft is not directly attached to the axis of the ball but is resting against its circumference. Assuming no slippage, the velocity of the circumference of the shaft is equal to the velocity of the circumference of the ball.

The shaft's angular velocity and rotation are now related to the motion of the mouse with the equations above, but the radius, R, is now much smaller and the shaft rotates much faster.

$$\omega = V/R1 \text{ radians per second}$$

where V= the velocity of the mouse and R1 = the radius of the shaft. As the shaft is made smaller, it rotates faster for a given mouse velocity.

How the Motion is Transmitted to the Sensors. The shafts that are rotated directly or indirectly by a wheel or ball are connected directly to motion sensors. These sensors can take a variety of forms and can be classified as one of two types: resistive sensing elements or optical interrupters.

5.3.1 Optical Interrupters.

Optomechanical mice use a device called an optointerrupter to generate the A and B quadrature signals. As shown in Figure 0-3 Optical encoder with quadrature outputs, the optomechanical system consists of a light source, usually a light emitting diode (LED), a photodetector, and the optointerrupter, which is connected to the rotating shaft of the mouse. The interrupter has a series of alternating black and white strips that allow light from the LED to shine onto the detector. As the interrupter rotates past the light beam, the solid segments between the slots will interrupt the beam and a series of voltage pulses will appear at the output of the detector.

A second quadrature output is obtained by using a second LED and detector that are offset from the first LED and detector by one-quarter of the angle of the radial slots or by using slots that are offset by one-quarter of their period, similar to a commutator's offset conductive segments. A mask with two holes through it may be used with the commutator to ensure that the light beams are in quadrature with respect to the rotation of the interrupter. The mask can be pierced or molded so that the holes are precisely 90 degrees out of phase.

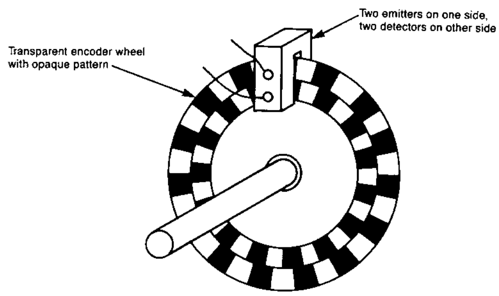


Figure 0-3 Optical encoder with quadrature outputs

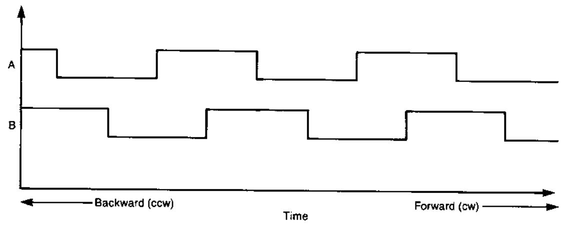


Figure 0-4 Quadrature signals

The output from the optical encoder is two quadrature signals, as shown in Figure 0-4 Quadrature signals. The direction can be sensed by examining the phase relationship of the two signals. If signal A is high when a rising edge occurs on signal B, then the motion is in the forward direction. The signals can be connected directly to an input port and all decoding and counting performed in software if the microprocessor is fast enough.

5.4 Trackballs

The trackball is used for similar purposes as the mouse. Its internal design is almost identical to a mouse and can be regarded as a mouse on its back and left in a stationary position. The trackball pre-dates the mouse and it is popularly believed that the mouse was conceived by turning a trackball upside down and moving it across a table surface. The main features of a trackball are shown in Figure 0-5 A trackball. A metal or plastic ball is mounted in a frame, with only a small portion protruding through the opening in the top of the frame. The ball is supported by two perpendicular rods so that when the ball is rotated left or right, one rod rotates, and when it is rotated forward or backward, the other rod rotates.

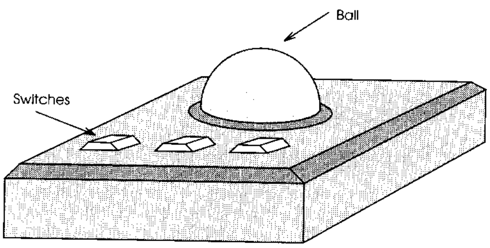


Figure 0-5 A trackball

The ball is completely free to rotate within its socket. It is operated by the palm of the hand and the movements sensed by the ball being in contact with two rollers inside the casing in the same manner as a mechanical mouse. The rollers' movements again are detected by sensing the rotations of discs attached to their ends. This sensing can be achieved by electrical contacts or by LEDs and photodetectors. Like the mouse, a trackball unit will usually include some buttons which can be reached by the tips of the fingers while the palm of the hand is resting on the ball.

For most purposes the mouse is more popular than the trackball but in situations where space is tight or no suitable surface is available the trackball is used. Currently it is commonly integrated into the casing of most laptop personal computers.

Advantages:

1. No Work space needed.
2. No missing mouse.
3. Often used to position cursor in lap-top and notebook computers, and ATC Radar displays, etc.

5.5 Optical Mice

Dirt on the work surface and on the ball bearings or wheels and slack and play in the mechanical linkages will cause slippage, resulting in loss of accuracy and erratic movement. The optical mouse eliminates these problems.

Work Surface. Optical mice generally use a special work surface in conjunction with an optical system and photodetectors to generate motion signals. The special work surface, or mice pad, is usually printed with a grid of lines, dots, or other geometric shapes that can be illuminated and focused onto a detector that generates signals proportional to the movement of the mouse.

There are many types of Optical Systems. The most common form is the Orthogonal Printed Lines.

5.5.1 Optical mouse with two-coloured line pad

In an orthogonal printed line pad, the optical mouse pad has a reflective surface and is printed with a grid of closely spaced orthogonal lines as shown in Figure 0-6 Optical mouse pad showing ink lines. The vertical lines are printed in one colour, the horizontal lines in another. The colours are chosen to absorb light at different frequencies, so that the mouse's optical detectors can differentiate between horizontal and vertical movement.

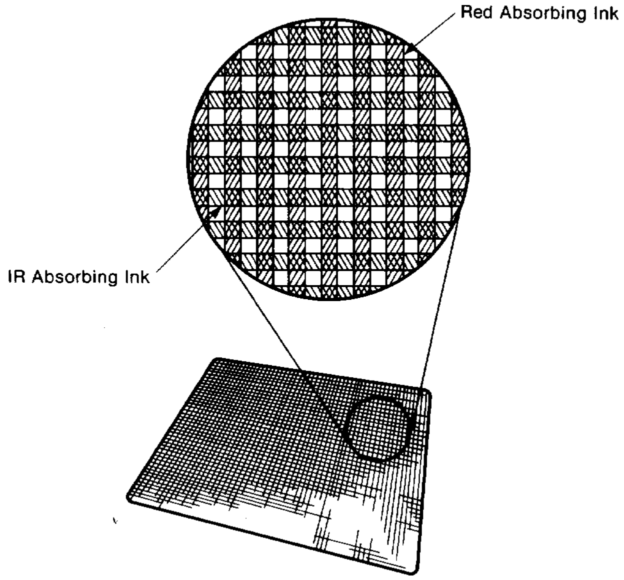


Figure 0-6 Optical mouse pad showing ink lines

The absorption spectra of the two inks should have a narrow peak of maximum absorption at its own wavelength and a very low level of absorption at the other ink's wavelength. The two wavelengths commonly used coincide with those of standard red and infrared light emitting diodes: 670 and 940 nanometers, as shown in Figure 0-7 Red and IR Spectral response of ink.

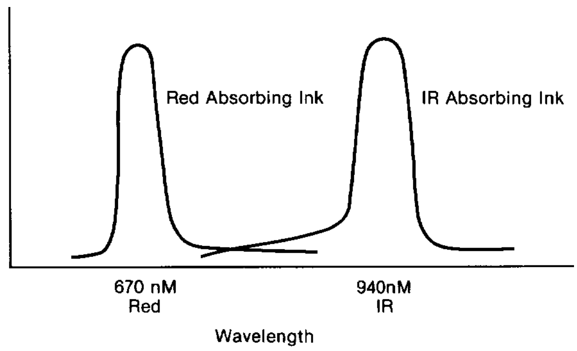


Figure 0-7 Red and IR Spectral response of ink

When the surface of the pad is illuminated as shown in Figure 0-8, light from the LED is reflected unattenuated directly from the mirror surface of the mouse pad, and is reflected, but attenuated, from the light absorbent ink lines. This light and dark object can be focused with a lens and mirror system to form an image on a four element photodetector. As the mouse is moved across the pad, the light and dark image will move across the elements of the detector, and each will generate a current that is proportional to the amount of light striking it.

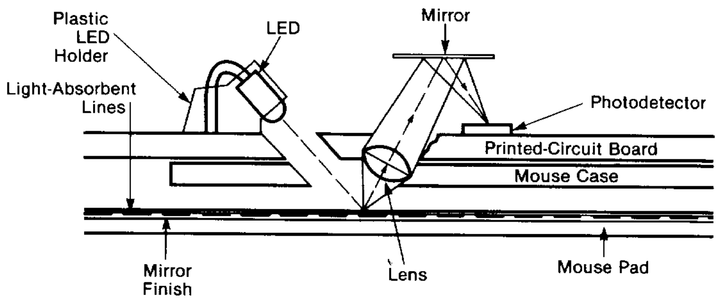


Figure 0-8 Internal mechanical structure of a optical mouse system

In an optical mouse as in Figure 0-8, this light and dark object can be focused with a lens and mirror system to form an image on a four element photodetector. As the mouse is moved across the pad, the light and dark image will move across the elements of the detector (as shown in Figure 0-9) and each will generate a current that is proportional to the amount of light striking it. These currents are usually very low, on the order of 50 to 100 nanoamperes, and must be amplified and converted to voltages before they can be easily interpreted. Operational amplifiers can be used to convert the photodiode currents to large voltages as shown in Figure 0-10(b).

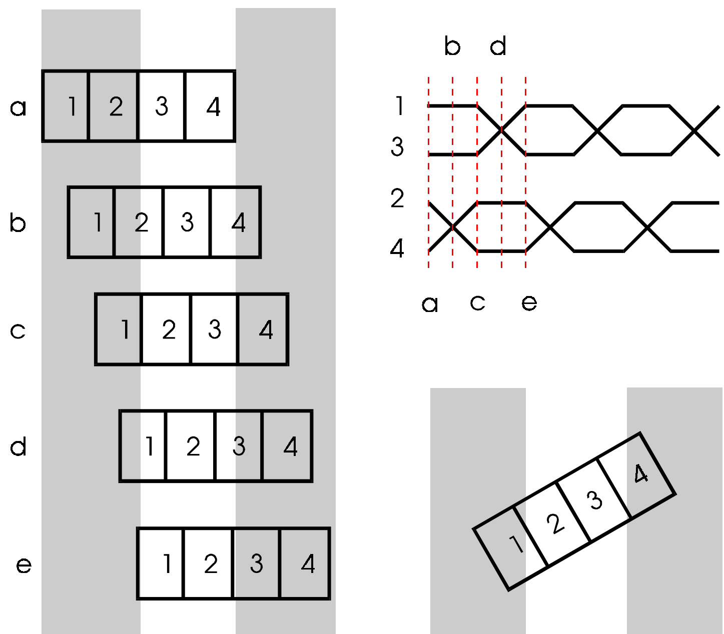


Figure 0-9 Four element photodetector and printed lines

If a simple magnitude comparison is made of the voltages generated by detector elements 1, 3, 2, and 4, the resultant waveforms will appear as two square waves in quadrature; the direction of motion determines which wave is leading the other.

The voltages generated by elements 1, 2, 3, and 4 and the results of their comparisons are plotted in Figure 0-10.

A second LED, lens, mirror, and detector can be oriented orthogonally to the first system to detect motion in the direction orthogonal to the first. The first LED would radiate energy at 670 nanometers, which would be absorbed by the 670 nM ink; the second would radiate at 940 nanometers and would be absorbed by the 940 nM ink. The energy from each LED would be absorbed by the appropriate ink; the other ink would be transparent to light of the wrong wavelength and there would be no absorption.

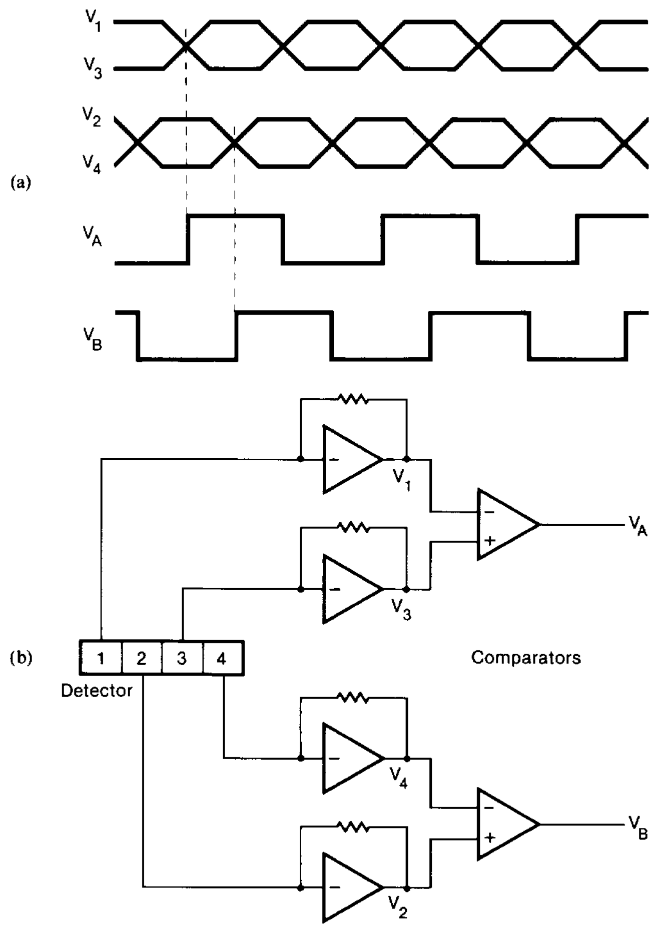


Figure 0-10 Quadrature signal generation in an optical mouse system

5.5.2 Optical mouse with one-coloured line pad

The above section discussed the optical mouse with two-coloured line pad. However, a variation of the design has produce optical mouse that can work with one-coloured lined pad. How? I will leave this to the discussion in your tutorial.

5.6 Electrical Outputs from Mouse

5.6.1 Types of Data

Quadrature signals are usually generated for a mouse, however, unless a relatively fast microprocessor is used which does not need to perform many other tasks while reading the encoder signals, rapid motion may be missed. A hardware implementation of the quadrature decoder, as shown in Figure 0-11 is usually required for the serial interface, removes the speed-critical tasks from the microprocessor.

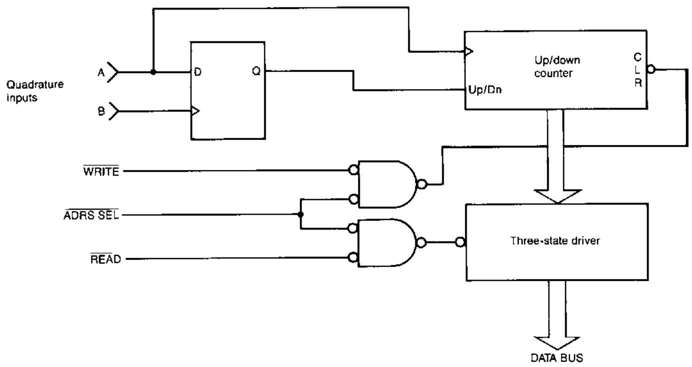


Figure 0-11 Basic quadrature decoder and position counter

The flip-flop detects the direction of motion by sensing the state of signal A at the rising edge of signal B. The flip-flop output provides a direction control signal to a counter, which counts the pulses. The counter can be cleared by the microprocessor by writing to the selected address. The counter then accumulates pulses, counting up or down depending on the phase relationship of the two inputs. The microprocessor can read the position via the three-state buffer (a basic input port) and then clear the count. The size of the counter determines how much motion can be accumulated between reads.

This simple circuit demonstrates the basic approach but has a number of weaknesses. If there is some jitters in the signals, erroneous counts can be accumulated. In addition, only one-fourth the available resolution is used. For maximum resolution, the counter should count both rising and falling edges on both the A and B input signals.

Hewlett-Packard's HCTL-2000 IC provides a single-chip solution for interfacing quadrature signals to a microprocessor system. It includes digital noise filters, quadrature decoders for full 4x resolution (both edges of both signals counted), and a 12 bit up/down counter. An 8-bit bus interface is included, which allows the counter to be read in two parts.

The electrical outputs from mice usually take one of two forms: parallel or serial data.

A mouse with parallel outputs presents its motion and switch information to the host computer over an interface that consists of one wire or data bit for each bit, or piece, of information. A three button mouse would have four wires for the X and Y motion information and three wires for the switch closure information, and additional wires for its supply voltage and ground.

A serial mouse presents its motion and switch data to the host over a single wire by using a specific serial communications protocol.

5.6.2 Parallel Outputs

The vertical and horizontal motion signals (Ya, Yb, Xa, and Xb) are generated from the quadratures signals. The switch closure signals are usually negative logic, that is, a logic "0" indicates that the user has pressed the switch. The switch signals may or may not be debounced, so the host software should include a debounce routine to let the switch settle to a valid state after it is first closed. Ten milliseconds is usually a sufficient debounce period for even the noisiest of switches.

5.6.2.1 Standard Pinouts/Connectors.

Standard Connector. The most common form of connector for parallel mice has been a 9-pin D-subminiature male plug. There is a limited number of connector pinouts and they are tabulated in Table 0-1 Quad Pinouts.

Table 0-1 Quad Pinouts

Pin Number	Mouse Systems	Logitech	Apple
1	+5V	+5V	Ground
2	Xa	Ya	+5V
3	Xb	Yb	Ground
4	Ya	Xb	Xa
5	Yb	Xa	Xb
6	L switch	Ground	Ground
7	M switch	M switch	Switch
8	R switch	R switch	Yb
9	Ground	L switch	Ya

5.6.2.2 Microsoft Connector.

MicroSoft uses a 9-pin mini-DIN connector; details are shown in Table 0-2 MicroSoft Mini-DIN Pinouts.

Table 0-2 MicroSoft Mini-DIN Pinouts

Pin Number	Function
1	+5V
2	Xa
3	Xb
4	Ya
5	Yb
6	switch 1
7	switch 2
8	switch 3
9	Ground

5.6.3 Serial Output

Electrical Characteristics. Serial mice will usually have an internal microcontroller or state machine that can interpret the motion and switch information and convert it to a simple serial output.

Serial mice generate outputs that are in one of two forms: RS-232 or TTL voltage levels.

In TTL output the inverted logic convention is the one most often used, and it implies that a 1 is .4V or less and that a 0 is 2.4V or greater. A common pinout is shown in Table 0-3 25-Pin D-Connector Serial Pinouts. Power for microprocessor taken from RTS and/or CTS lines.

Table 0-3 25-Pin D-Connector Serial Pinouts

Pin Number	RS 232 C Abbr.	Function
1	GND	Protective Ground
2	TD	Data from host
3	RD	Data from mouse
4	RTS	Signal ground

5.6.3.1 Communications Protocols.

Common Protocols. Serial mice transmit data in a variety of packet sizes and protocols. The most common packet sizes include either three or five bytes of data; the data is transmitted in a sequence that first sends sync and switch information, then X and Y motion information. The most common mouse protocols are listed below.

5.6.3.1.1 Microsoft Compatible Data Format.

Protocol: The Microsoft Compatible data format transmits relative motion information in the form of three seven-bit bytes.

Direction of Motion: Positive motion is defined as being to the right in the X direction and upward, or toward the right in the Y direction. Bit 7 (MSB) of the X and Y bytes will be 0 for positive motion and 1 for negative motion.

The X and Y motion information consist of eight bit two's complement binary numbers. The first byte contains the switch information and the two most significant bits of the X and Y data. The next two bytes contain the lower six bits of the X and Y data. The contents of the three bytes are shown in Table 0-4 Microsoft Protocol.

Table 0-4 Microsoft Protocol

Bit No.	MSB 6	5	4	3	2	1	LSB 0
Byte 1	1	L	R	Y7	Y6	X7	X6
Byte 2	0	X5	X4	X3	X2	X1	X0
Byte 3	0	Y5	Y4	Y3	Y2	Y1	Y0

Parity: None

L, R: Left, right switches; 1 = switch pressed

X0-X7: X distance

Y0-Y7: Y distance

5.7 Advantages and Disadvantages of Mice and TrackBalls

Table 0-5 Advantages and Disadvantages of Mice

Advantages	Disadvantages
Work in small spaces	Require space beside keyboard
Can modify control-display gain	May have low resolution and information transmission rates
Inexpensive	Unnatural drawing movements
User can keep eyes on screen	Relative mode only
Mechanical mice use any surface	Optical mice require grid
Optical mice are noiseless	Mechanical mice produce noise and pick up debris

Table 0-6 Advantages and Disadvantages of the Trackball

Advantages	Disadvantages
Direct tactile feedback	Not well suited for drawing
High resolution	No three dimensional input
Requires little space	
Allows rapid cursor positioning	
Can modify control display gain	

5.8 Joystick

The joystick is also a positional device which can be used to control the position of an on-screen cursor. It is a short stick which, like the eponymous aircraft control, is either gripped or operated by the tips of the fingers and can be moved in all compass directions. An example of a joystick is given in Figure 0-12 A joystick.

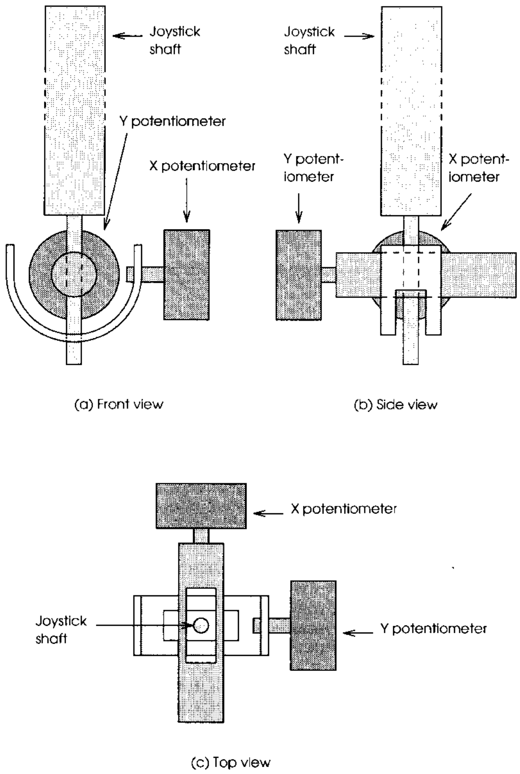


Figure 0-12 A joystick

Because small movements of the stick become enlarged when translated to a cursor, it is difficult to achieve accuracy in this manner. The stick may also fall slightly if it were left tilted. For these reasons the joystick is not used to give absolute positions but relative ones. It is also sprung so that it returns to its central position when released. The movement of the stick can be used to cause the cursor to move in the same relative direction and to stop moving when the stick is back in the middle. The movement of the stick is used to give a direction and the size of the movement is used to control the speed that the cursor moves. In this manner accurate positioning is possible.

A common use of joysticks on personal computers is to control features in games - particularly flight simulations - where the movement of a character or object is controlled in a similar manner to that just described for cursor control.

Some joysticks employ a third degree of movement in that the joystick can be twisted. Like the normal movements, the twisting can be absolute, like turning an ordinary rotary control, or it may return to a central position upon release. Most joystick units, like mice and trackballs, will also sport one or more buttons. Many joysticks work by turning two potentiometers which are at right angles to each other. These are analogue joysticks. The two potentiometers are read to obtain X and Y coordinates. The mechanics of achieving this are shown in Figure 0-12 A joystick which displays three views of the way in which the joystick shaft connects with the two potentiometers' controlling spindles. The shaft narrows when it enters the joystick unit's casing so that it can pass through the (enlarged) spindle of one of the potentiometers. In Figure 0-12 this is the spindle of the Y potentiometer. Looking at Figure 0-12(a) left/right movements of the shaft will turn that Y potentiometer's spindle. The narrowed joystick shaft then continues through a semicircular strip which has a hole in it sufficient to allow the movement just described. The view in Figure 0-

12(b) is at ninety degrees to that in Figure 0-12(a) and looks directly down the spindle of the other potentiometer - the X potentiometer. In Figure 0-12(b) a left/right movement will move the X potentiometer's spindle and, as is more clear in Figure 0-12(c) which is a view from the top, the first hole that the shaft went through is sufficiently long to permit this movement. This left/right movement in Figure 0-12(b) moves the semicircular strip which is connected to the (shortened) spindle of the X potentiometer.

Movements of the joystick shaft in any direction will, in general, cause both potentiometers' spindles to turn, as is perhaps clearer in the view down the joystick shaft from above in Figure 0-12(c). A voltage is presented to the centre terminal of both potentiometers. The two end terminals of each potentiometer are read to obtain the X and Y values. If a button is present then this same voltage is applied to the button's switch and the other side of the switch is read. Then the cable to the joystick contains:

- voltage out
- two X voltage returns (analogue values)
- two Y voltage returns (analogue values)
- one voltage return for each button (digital on/off value).

The joystick just described is an analogue joystick, as it provides an analogue (continuous) voltage to specify the X and Y positions. Digital joysticks also exist and, instead of moving the spindles of two potentiometers, they operate discrete switches. For this reason they are sometimes referred to as joyswitches. The joystick shaft is moved in the same way as before but now makes contact with four switches positioned at the top, bottom, left and right locations in the unit's case. Some have eight positions for greater resolution of direction. The types with four switches are arranged so that, for example, in the North-West position, both the North and the West switches are activated and so eight different directions are possible. A similar arrangement with the eight switch variety gives sixteen discrete values for the joystick direction.

This digital joystick facility is alternately provided by a pad of four pressure switches arranged at the four compass positions. This produces the same information as the digital joystick and, by pressing two adjacent switches simultaneously, a total of eight directions can be input.