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Studies on Mechatronics

History of Computer Pointing Input Devices

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Abstract

The aim of this research is to explain the history of computer input devices, starting from the beginning of their development (fifties and sixties), following then their historical and technological evolution in the years. The purpose is also to give a logical way through the development that various kinds of computer controller had, comparing then their potential, application and diffusion in the society. In particular will be studied the motivations which lead the mouse to be chosen as the most common used computer input device, how did it evolve from the very first mouse, up to mechanical ball, optical and 3D mice. How joystick evolved, when and how did the force feedback to the user appear, and in which ways this can be created (for example vibration). Coming near to the last years with the newest haptic paddles that permit to input movements and rotation in all six degrees of freedom, analyzing their characteristic and possibility for their actual and future applications.

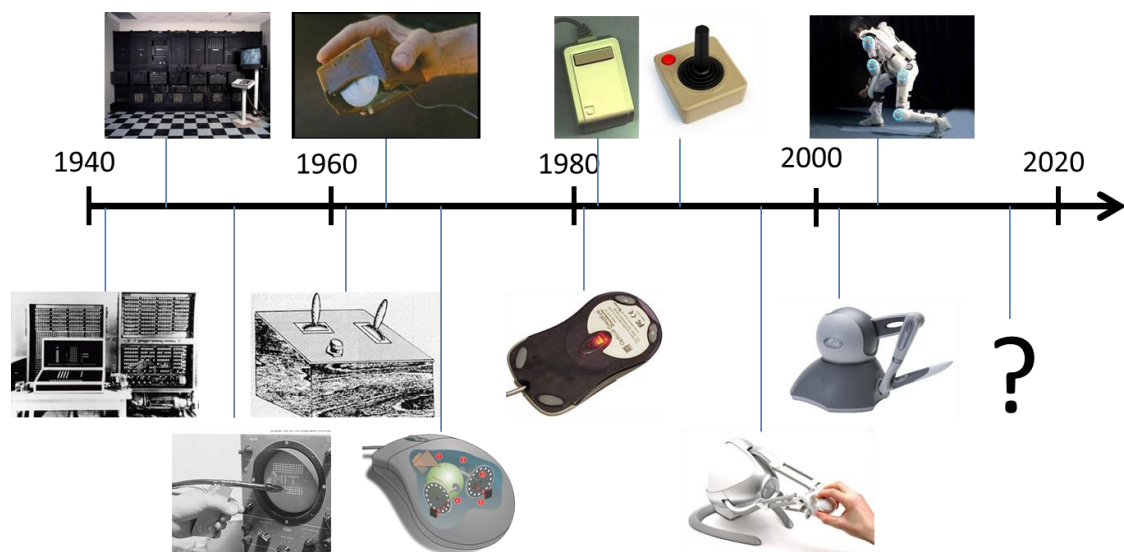


Figure 1 Timeline with the devices threated in this paper, this will also be a sort of "fil rouge" (guiding thread) through this paper.

Introduction

Many different communication channels can exist between man and computer. These can take place through the human senses (tact, sight, voice, movements), or combining each other giving the possibility to simplify the interaction between real and virtual world. These communication channels have been developed during the years: at the beginning only keyboards -or similar devices- were used, but during the fifties-sixties with the appearance of displays the first graphical input devices like light pen, joystick, and mouse have been introduced and lead to a more and more intuitive access of electronical resources. The first touch screen and feedback system will appear some years later, in the seventies. All these devices have then developed in many different ways and combinations, leading to last ones which are (almost) able to voice-tell the commands, or input information to the device with movements. Many of these systems are currently used in various applications, some of them (teleoperations, force feedback) will be presented in this paper.

1 First Computer

The first problem encountered on computer input devices is: how do we define what a computer is? There is no right answer to this question, and it depends on subjective definitions. Here two possible definitions:

1)

A device that computes, especially a programmable electronic machine that performs high-speed mathematical or logical operations or that assembles, stores, correlates, or otherwise processes information¹.

2)

A computer is a programmable machine designed to sequentially and automatically carry out a sequence of arithmetic or logical operations².

In this paper we are interested in digital computer, which began to develop in the forties, the evolution of pointing input devices begins some years later.

A problematic Example is the Jacquard Loom (1801): a programmable unit used during the Industrial revolution, it is capable to "assembly" different textures, and can be considered a computer according to definition 1, but it would not according to definition 2 because it is not able to carry out arithmetic or logical operations.



Figure 2 Jacquard Loom

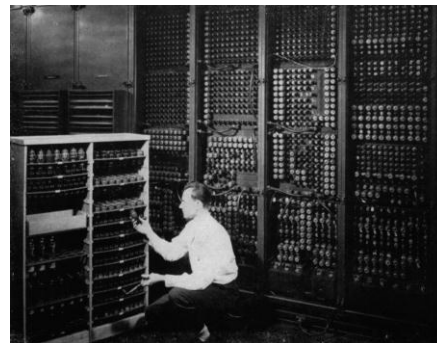


Figure 3 A computer in almost all definitions: the ENIAC.³

¹ Source: The American Heritage Dictionary of the English Language

² Source: <http://en.wikipedia.org/wiki/Computer>

³ Image Source:

<http://www.plantsciences.ucdavis.edu/amr21/AMR21newsite/AMR21/NewEALpages/Lect03.html>

2 First generation input devices

Depending on different subjective visions, it is difficult to establish the exact moment of creation of many input devices (like joystick or light pen) because often these are developed in small researches, which are not directly related with the input device itself, but with other focus. When there is agreement on the date of appearance of an object it will obviously be taken (see the case of the first mouse, chapter 2.3), but there are also cases where this choice is not so clean and unique, there the priority will be taken basing on substantial changes in the technology used, for example for the light pen, (chapter 2.1), or in case of a high popularity of the device. Starting from forties, the research on computer, and then on different input devices, has done much changes and brought many improvements. All this implies an higher difficulty in dating the inventions. Even dating the first computer is a difficult thing: it is usually taken to be compared on the forties-fifties, but depends strongly on subjective definitions.

2.1 Light pen

The first pointing input device created was the light pen, this kind of device was already used in the thirties to recognize the presence of light on a surface, but its use as an input device for computers is dated between 1949-1952 [13], as a part of the Whirlwing project at the MIT (Massachusetts Institute of Technology), under the leadership of Jay Forrester (figure 4). The working principle is based on optics: a photo sensor inserted in the device is able to recognize changes of brightness at a velocity much higher than human eyes, the screen is



Figure 4: The first input-device ever was a light pen⁴

constantly updated from the video card in an ordinate way, let's say starting from top left and writing the whole screen line by line until bottom right. When the update reaches the pointed pixel, the photo sensor recognizes a change of luminosity and sends a signal; the

⁴ Image source: <http://www.asme.org/kb/news---articles/articles/computer-aided-design-%28cad%29/the-future-of-design>

computer calculates the time at which the light has changed, and can then reconstruct the coordinates that were being updated, and so the position of the pen. Notice that the changes of luminosity in the pixels are not visible with human's eyes because of the high frequency of screen update.

2.2 Joystick

Similar to the light pen, the invention date of the joystick is uncertain: the first ones were pure mechanical, used in the aviation during the first years of the 20th century; the first electronical joystick instead appeared in the forties, when the military interest on new technologies was high due to the surrounding World War 2. It is in the German army, where this kind of pointing device is first used: its purpose was to help teleguided missiles reaching this target ([14], figure 5). As an input device there are few sources describing joysticks, until the 1961, when Alan Kotok (MIT) developed one of the first videogames, and the first joystick used as a computer input device [5]. The code of "Spacewar!", this is the name of the game, has been translated in a java application which can be found at (<http://spacewar.oversigma.com/>)

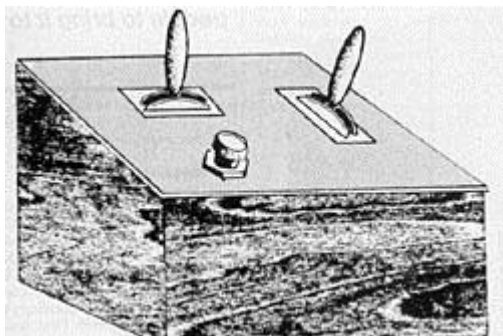


Figure 6 The first input-device joystick of Alan Kotok: two potentiometers and a selection (shoot) button. [5]



Figure 5 Henschel 293: one of the first teleguided missiles of the history.⁵

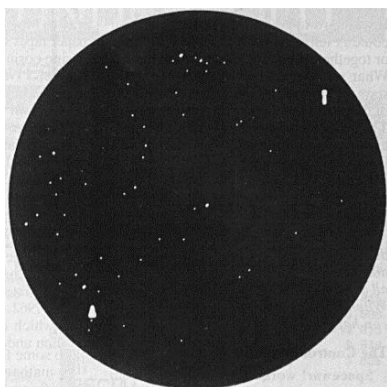


Figure 7 A gameplay view of Spacewar! the purpose of the game was to shoot the adversary avoiding the central gravity (sun) zone

⁵ Image source: <http://www.1jma.dk/articles/1jmaluftwaffegroundweapons.htm>

The working principle is simple: two potentiometers (figure 8) are positioned perpendicular each other, and are responsible respectively of the movements in the horizontal and vertical movement of the pointer (ships in the original videogame) (figure 7). To make the system easier to use, two sticks are used to move the position of the potentiometers. Particularity of this joystick is that the user uses both hands to move the device, and the addition of a button that permits the selection of elements on the screen.

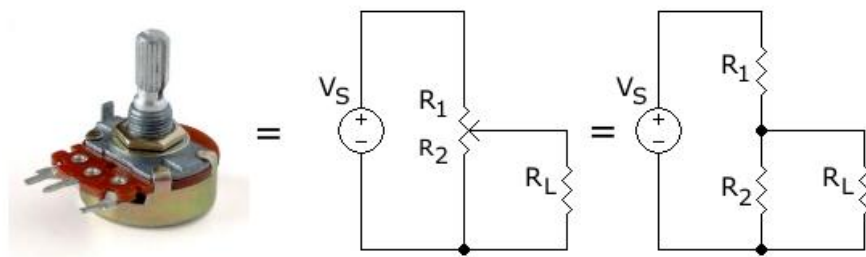


Figure 8 Potentiometers transform a movement in the space into different voltage, it is often a sliding resistance connected to a constant voltage source (battery). It can be used as linear or rotational.

- V_S : Voltage source;
- $R_1; R_2$: sliding resistance;
- R_L : load resistance.

There are two methods with which the signal can be used and interpreted from the computer:

1.

Absolute: every position of the potentiometer corresponds to a coordinate, let's say: if the vertical-potentiometer voltage is zero, the pointer is on the bottom of the screen, if it is maximal, it is on the top. This is best explained by following relations:

$$X_{coord} = \frac{V_{pot,x}}{V_{max,pot}} X_{res}$$

$$Y_{coord} = \frac{V_{pot,y}}{V_{max,pot}} Y_{res}$$

Where:

- V_{pot} : voltage given from the potentiometer
- $V_{max,pot}$: maximal potentiometer voltage
- X_{coord}, Y_{coord} : screen resolution (pixel)

2.

Rate: the voltage given by the potentiometer proportional to the velocity of the cursor, or explained with following relations:

$$V_x \propto \frac{V_{pot,x}}{V_{max,pot}}$$

$$V_y \propto \frac{V_{pot,y}}{V_{max,pot}}$$

Where:

V_{pot} : voltage given from the potentiometer

$V_{max,pot}$: maximal potentiometer voltage

X_{coord}, Y_{coord} : screen resolution (pixel)

According to some non-verifiable sources, the name of the joystick originates from French pilot Robert Esnault-Pelterie, which has reported first the term in his diary in 1910; the composition of joystick is assumed to come from another aviation-pioneer: A.E.George, from which the name George-Stick then evolved to Joystick.

2.3 Mouse

The last kind of the first generation input device is the mouse. Differently to the joystick or the light pen, the inventor are overall recognized to be Douglas Engelbart and Bill English, which presented their work in the year 1965, at the Stanford Research Institute (Menlo park, California) [13]. The purpose of the research was one of the first studies about human and computer interaction, in which pointing input devices were confronted in order to find a way to simplify and improve computer operation, such as text editing. Their solution to point and select on the computer screen is considered to be the first mouse (figure 9).



Figure 9 The first mouse was a wooden case of 2"x3"x4", about 5x7.5x10 cm, mouse was the name given to the device in the laboratory, due to its aspect.⁶

⁶ Image source: <http://www.resonancepub.com/computers.htm>

The working principle is similar to the joystick: two potentiometers are perpendicularly placed, and responsible of the movements on horizontal and vertical directions, with a button to select text. The main difference is that the potentiometers are connected to wheels which roll while the user is moving the mouse on the table, however this is a huge change for the user: the system intuitivity is much better, and the user feels the movements he is doing with the hand, seeing the results on the screen. This brings to a much better practicality and usability in the interaction.

2.4 First comparison

The research of Engelbart compares and studies for the first time the possible differences in the communication with a virtual machine. Experiments were supposed to test the ability in modifying and composing real-time data (especially text), testing speed, precision and intuitivity of the following input devices:

- Mouse
- Joystick
- Light pen
- Knee control (figure 10)
- Grafacon (figure 11)

The idea was then to improve the speed and intuitivity and decrease errors of the communication and then apply the results in the work world, simplifying all-day computer operations.

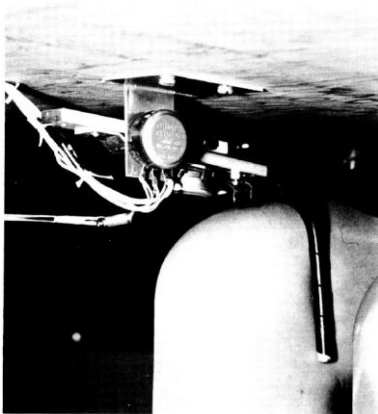


Figure 11 The knee control used in the research, based on two potentiometers

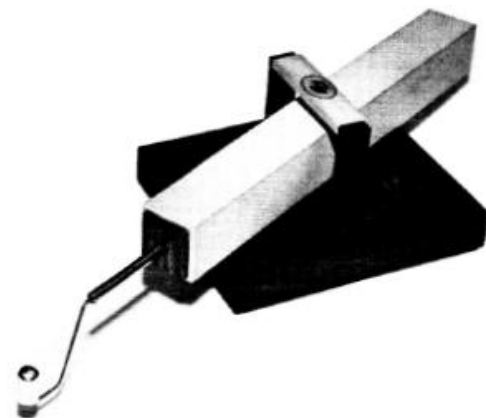
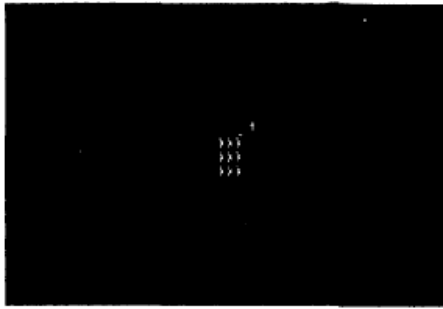
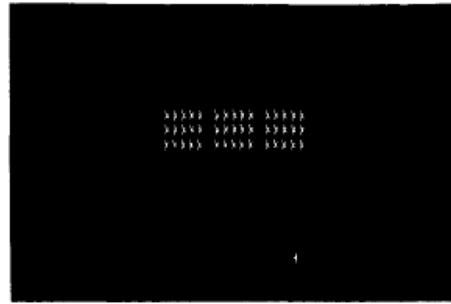


Figure 10 Grafacon is another potentiometer-based input device, but works in polar coordinates, however in this comparison the voltage is transformed in horizontal and vertical movements: to write a straight line the user had to input an arc.



"CHARACTER MODE" OPERATION
SHOWING THE TARGET (MIDDLE X)
AND BUG (PLUS SIGN)



"WORD MODE" OPERATION. THE TARGET
IS THE MIDDLE FIVE X's

Figure 12 an example of test performed during the comparison: a target, which is formed of X's is displayed on the screen. The user is asked to press the space bar and to reach the target as quickly as he can doing this only with one hand. Using this method the speed and the accessing velocity from keyboard to pointing device are measured.

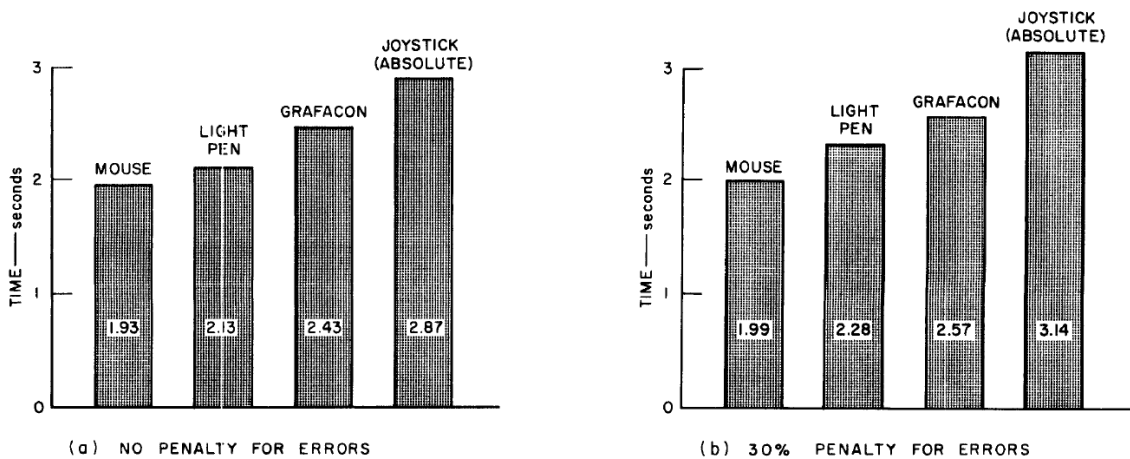


Figure 13 Speed of the devices: the mouse is more quickly than the other input devices, but the difference is small.

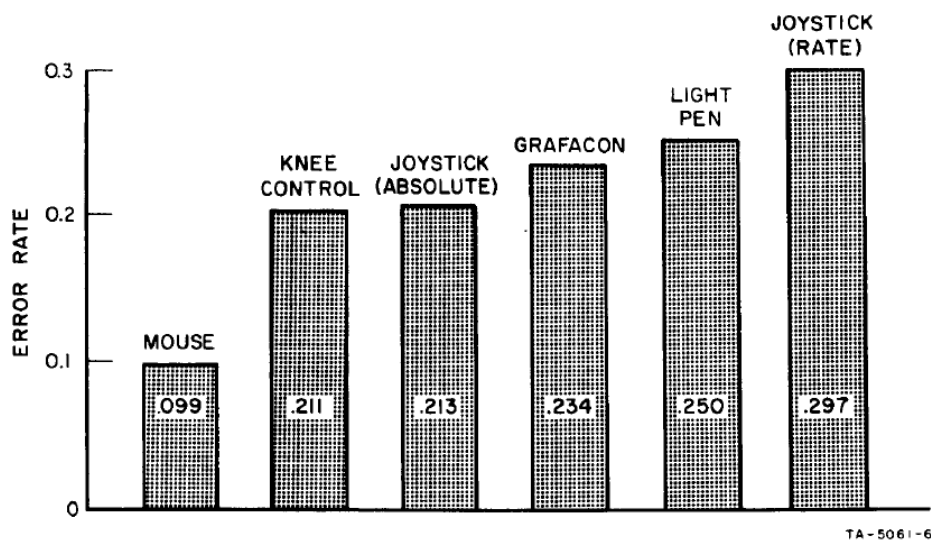


Figure 14 the mouse shows a great difference in the error rate: the user can reach better accuracy.

3 Evolution of the first generation

3.1 Ball mouse and optical encoder

While the research on the first mouse was taking place, an European evolution of the mouse appeared during the development of the TR440 Computer [4]: the ball mouse, that simplified drawing simple vector graphics on the screen, like simple geometrical figures. In older mouse version the movements were restricted to horizontal or vertical, the adoption of the ball instead brings more liberty in the movements and permits to the user to move the mouse in any direction. This ball-mechanical mouse and particularly the Xerox-Model designed in the seventies will be a fundamental part of commercial mice in the nineties. Another important step done by Xerox's researchers is the optical encoder, which solved the problem of limited range utilization; this was due to limited range of the potentiometers (figure 8). The optical encoder (figure 15) sends digital information to the computer: the actual velocity and direction of the mouse is calculated from the square pulses generated in the rotation of the encoder disk. Another advantage is that the friction inside the mouse is far less than with potentiometers.⁷

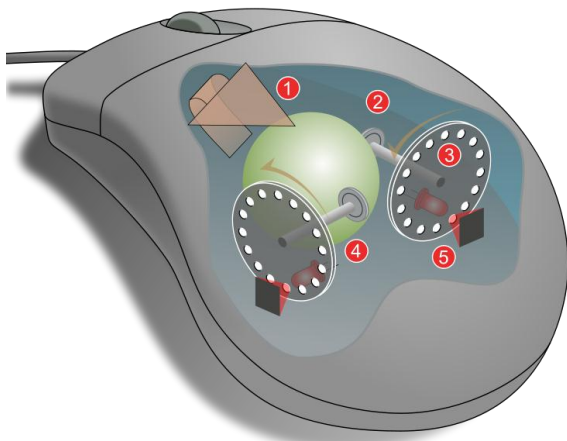


Figure 15

1. moving the mouse turns the ball
2. X and Y grip the ball and transfer movement
3. Optical encoding disks with holes
4. infrared LEDs shine through the disk
5. Sensors gather light pulses to convert X and Y vectors

A New opto-mechanical concept and a design which will be used in the nineties for most of the mouse: notice that to determine the direction in which the mouse is moving, two detector per encoder disk are needed.

3.2 Lisa Mouse

Apple's Lisa mouse is the first wide-used computer pointing input device, in this mouse there is no substantial difference from the Xerox's model, except the cost: 20 times less. This reduction of costs is also an important step in the diffusion of mice, which can now (eighties) be bought by much more people than before.

⁷ Image Source: http://en.wikipedia.org/wiki/Mouse_%28computing%29

3.3 Optical mouse

The first optical mouse has been developed in 1981 at Palo Alto from Richard F. Lyon [8]. The working principle is simple: a chip takes photos every small step of time, and compares the images to recognize where the mouse is moving (figure 16). Due to the use of this technology, optical mouse does not work on perfect or reflecting surfaces, but needs some pattern on the table to reconstruct the movement⁸. A popular belief is that all optical mice are laser mouse. This is not the case: most of the optical mice are based on an infrared LED and this perfectly explains the red light on the bottom of the mouse. The most important advantages are that this device needs less maintenance and has higher lifetime, due to the fact that the mechanism is isolated, so that dust and dirt cannot enter into the mouse. It is also lighter and cheaper than a ball mouse: mechanic requires high precision finitures, and requires more material.

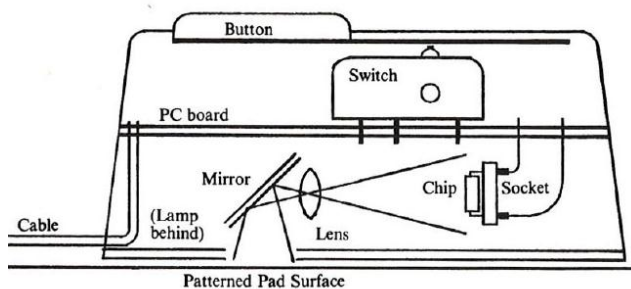


Figure 16 schematics of an optical mouse: the light from the Lamp (often LED or Laser) is reflected on the surface, and an optical sensor (chip) converts the image.

3.4 Light gun

Light guns are the evolution of the light pen: the working principle is the same, but the technology evolved permitting to the distance to be greater, the gun can be hold on the hand a bit away from the screen. It is a huge step nearer to the reality to play a light-gun game. Periscope (1968) (figure 17) is the first game that used this kind of input device, and one of the first "quarter dollar game", where the guest pays every game he begins. The light gun will then be used for many other shooter games. This technology will then remain in arcade room, and will not reach many homes.

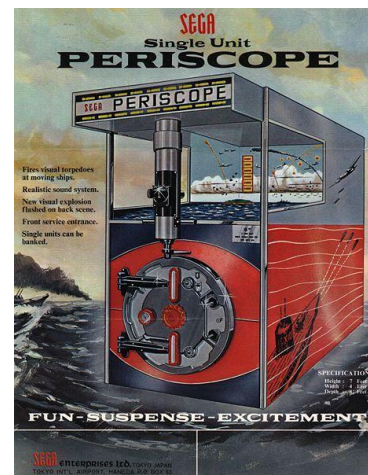


Figure 17 The light gun is hidden in the periscope device, which is used to aim enemy ships.⁸

⁸ Modern mice can be used practically on every surface: the sensor is able to detect very small imperfections

⁹ Image source: <http://www.giantbomb.com/reviews/>

3.5 Joystick

Joystick had no great evolution over the years, except for the single stick hold and the digital joystick which output can only be 0 or 1. The main evolution is in the usage: in fact new controller are composed from more than one joystick or button (figure 18).



Figure 18 A good example: the PlayStation 2 controller, composed from two analogical and one digital joystick with many buttons

3.6 Second comparison

As shown in the last pages many input devices had a great evolution during sixties and seventies; and many researchers developed to different input de-vices. A new study on upcoming input device was conducted in Palo Alto Research Center [11]. The article is an in-depth of the research of Engelbart [13] which is not considered to be exhaustive. The main critics are:

- Only mean and no standard deviations in the experiments
- No investigation on distance effect on speed and errors
- Two targets, but no distance-target size correlation with positioning speed

Similar to the experiments of Engelbart [13] (chapter 2.3), the speed of various input devices is tested, but this time the data is analyzed from a statistical point of view (mean and variance and learning curves are given). Furthermore, it is calculated the influence of accessing time to the device, the distance and size of the target, with high number of experiments. The test results are shown in image (figure 19) was asking the users to strike the space key on the keyboard, and then switch to the pointing device to select a target on the screen. It is important to notice that the mouse has the slowest homing time, but this time compared to the positioning time results insignificant. This research confirms that the mouse is more quickly than joystick, and positioning keys as a pointing input device even in 1978.

Device	Movement time for non-error trials (s)						Error rate	
	Homing Time		Positioning Time		Total Time		M	SD
	M	SD	M	SD	M	SD		
Mouse	0.36	0.13	1.29	0.42	1.66	0.48	5%	22%
Joystick	0.26	0.11	1.57	0.54	1.83	0.57	11%	31%
Step Keys	0.21	0.30	2.31	1.52	2.51	1.64	13%	33%
Text Keys	0.32	0.61	1.95	1.30	2.26	1.70	9%	28%

Figure 19 M: mean; SD: Standard Deviation. Homing time is the time which occurs between strike on the keyboard and first movement of pointing device, positioning time: from the first movement to target selection. Higher homing time of the mouse is due to the higher distance from the keyboard.

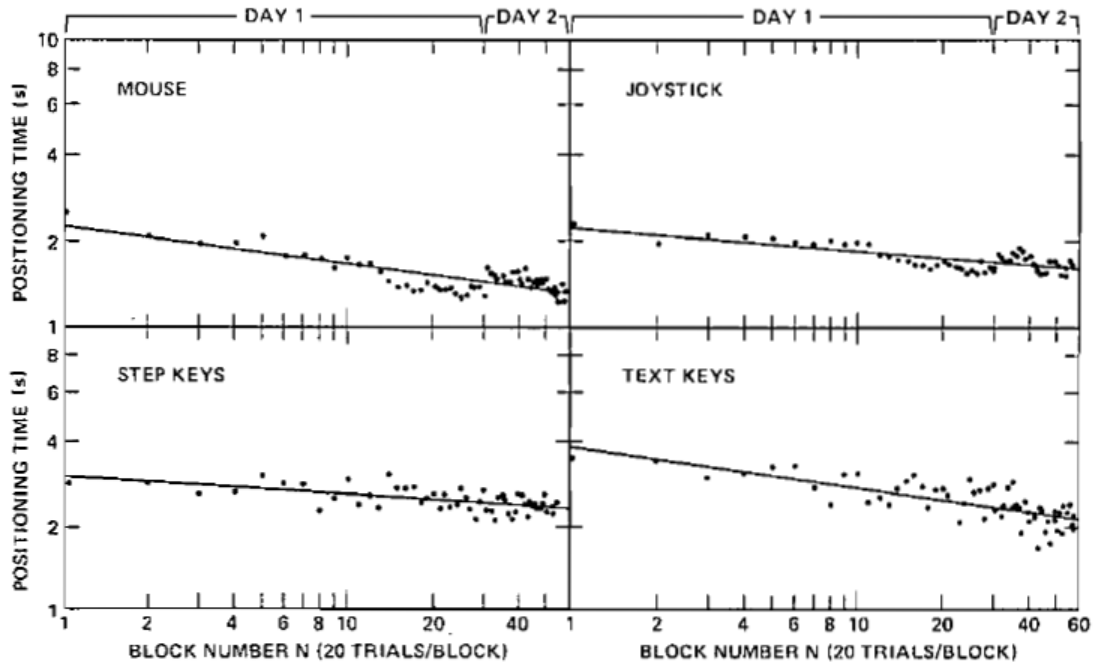


Figure 20 Learning curves for the device tested: mouse shows best results, in particular in the second day

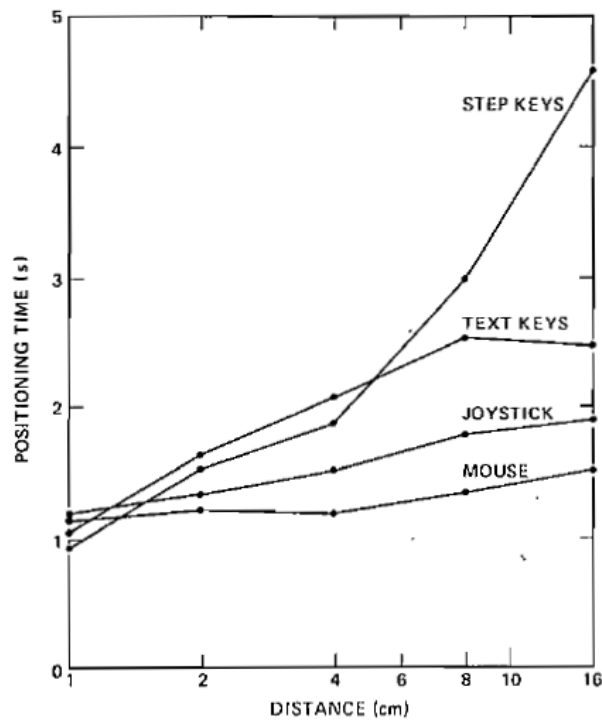


Figure 21 Dependence of the target distance on the positioning time.

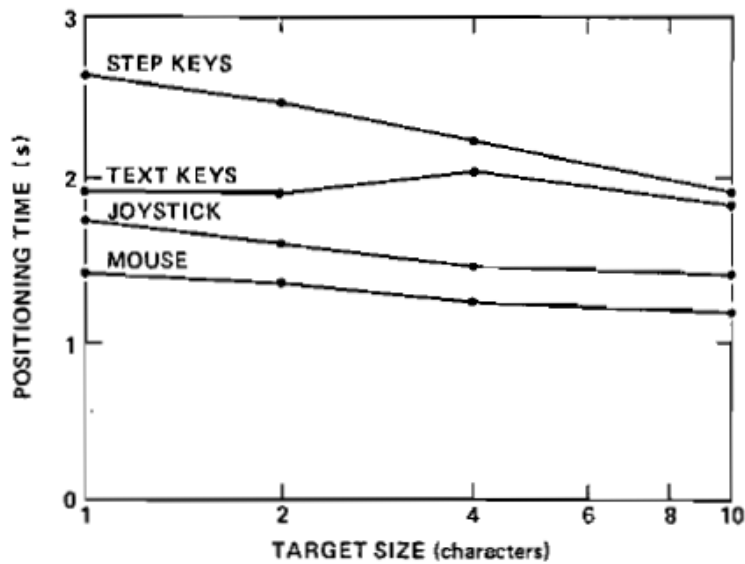


Figure 22 Dependence of the target dimension on the positioning time, the mouse confirms its precision.

4 Moving to the 3D world

The main limitation in the input devices shown here are the degrees of freedom (DOF¹⁰): in fact most of them only work in two dimensions, with no possibility to input "in and out" or rotation movements to the computer. Starting from the eighties the 3D imaging and shaping of objects is investigated, and so also more three and upper DOF devices are to determine or visualize tridimensional images on the screen. To improve the intuitivity and usability of 3D visualization programs and have realistic manipulation of the object 6 DOF are needed, so that the user can move the input device in the same way he would move the object on the screen.

4.1 Bat mouse

This is exactly the idea at the basis of the bat mouse [1] (figure 23): in fact it is able to input to the computer the three translational and rotational movements, permitting the user to freely move it in a 3D space. The position of an object on the screen is directly connected to the position and orientation of the bat mouse. This is useful for the scope of the research, which was to investigate on the problem of the virtual handling of 3D objects and shapes. The working principle is based on six position sensors, with which the controller can reconstruct the position and orientation of the bat.

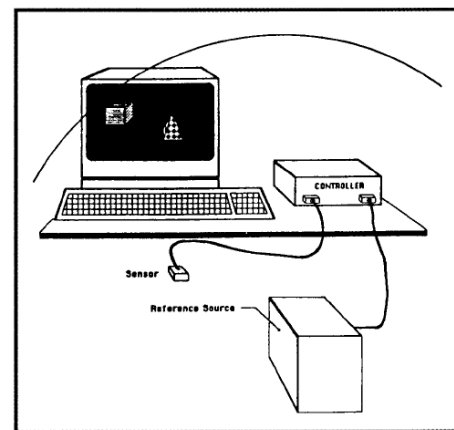


Figure 23 The 6DOF mouse, called bat because it is a "flying mouse".

4.2 Haptics

These kinds of devices are used to make the user feel forces, vibrations or motion. Doing that it is possible to send a feedback interacting in a bidirectional way with the user. It is also possible to send messages to the user (i.e. errors, or indications). The advantage of these devices is that they can simulate situation similar to the reality. It is possible to simulate object, walls or different friction situation, such as being in water. In haptic technology there are many different devices, with more or less DOF, actuators or linkages. Their development has not a precise data, as most of mechanical joystick already have a physical feedback, but the first research in the field of this kind of devices

¹⁰ How many independent movements can be done from a system. For example a man walking on a surface has 3DOF: 1) forward-backward; 2) left-right; 3) turn himself

is to be ascribed to R.C. Goertz, at the beginning of the fifties [10]. One of the greatest field where haptic devices are used are teleoperations, where the operation is executed from a surgeon that does not interact directly with the patient but works in a virtual environment, and is then a robot that actually executes the operation. This method can bring improvements on the accuracy of the surgeon (for example scaling the movements from a factor 10), or give the possibility to operate from thousands of kilometers of distance.

4.3 3 DOF Haptic paddle

According to [12], the delta robot configuration showed in figure 25 was introduced from Raymond Clavel [Clavel,1989], and is the basis of the Falcon Novint. The Falcon has been developed from Novint Technologies, to be an alternative to the mouse. It is being publicized to be a good game controller, but has (still?) not a high popularity. It is usually used in the research in three DOF parallel dynamics robot applications. This device is able to move in the 3 translational coordinates, and it is able to be transparent to the user¹¹, giving a force feedback, or simulating real situations.

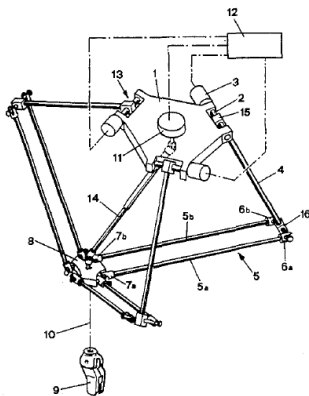


Figure 24 The delta motor configuration is composed from three linear or rotational actuators which are connected to end end effector so that it can only move in the three transitional degrees of freedom. The delta robot configuration was introduced by Reymond Clavel in 1987 [3] [12] and uses a parallel kinematics approach.



Figure 25 the Falcon Novint, a possible 3D alternative controller to the mouse.¹¹

¹¹ Transparency: the ability of a device to hide the dynamics of the actuators, and of the whole device to make the user feel only the virtual reality which has to be reconstructed.

¹² Image source: http://www.bit-tech.net/gaming/pc/2007/12/07/novint_falcon_limited_edition/2

4.4 6 DOF haptic paddle

Shown in figure 26 is an early 6DOF haptic manipulator [6], which differently from the Falcon Novint (figure 25) works with serial kinematics. It was developed in 1994, and is used to investigate 3D shaping: a huge research field for the haptic world. The working principle bases on 6 different motor which are responsible of three translational and three rotational movements. The advantage of a serial kinematics is the large workspace of the machine, but comports more problems in the feedback forces due to the higher friction of the motors, and high inertia because of the heavier moving parts.

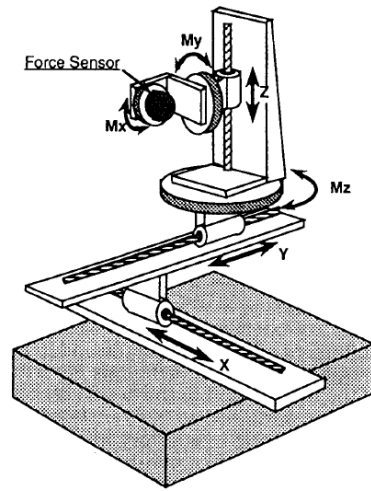


Figure 26 differently from the Falcon Novint this device uses a serial kinematics approach; i.e. the movements sum up to reach the final wanted displacement.

5 Conclusion

Now that the evolution of some input device has been presented, it is time to see why the way of input devices went this direction. A first question is "why did not these devices evolve more quickly?" The answer to is often a cost matter: most of the devices here were introduced in research project, which did not really care about if the price is too high for common people, and computer were still not cheap enough to stimulate input device diffusion. The moment of change was when the display and operating system could support a graphical input device, and the consequently "price sinking" from factor 20 or more. A second important conclusion would be say what is the best input device actually, however his question has no right answers: the input devices developed in different forms to catch particular application needs: a mouse is not good enough to play a car game, so there is a joystick on new game controller, a joystick is not the best way to change channel on a television, so we use remote control, which is nothing else than a keyboard, but a keyboard is not enough visually control a computer. Every controller has its own best application; a possible choice to it is shown in figure 27:

<i>Device</i>	<i>Type</i>	<i>Best Application</i>	<i>Limitations</i>	<i>Comments</i>
Keyboard	QWERTY	Data and text entry	Poor postures	Conventional
	Split	Improved arm-hand postures	Learning required	Preferred alternative
	Chord	Minimal finger travel, portability	Learning required	Limited evidence
	Scooped	Shorter finger travel, better posture	Learning required	Limited evidence
	Smooth/soft	Small footprint, portability	No kinesthetic feedback	Limited evidence
Nonkeyboard	Mouse	Pointing & selection tasks	Demanding control	Standard choice
	Trackball	Pointing & selection tasks	Slower than mouse	First alternative choice
	Joystick	Tracking & pointing tasks	Sensitive to tremor	Not recommended
	Trackpoint	Pointing, small footprint	Hard to control	Not recommended
	Touch pad	Display-control compatibility	Selection accuracy	Poor finger item selection
	Touch screen	Intuitive, menu selection	Typing accuracy	Direct user input on display
	Light-pen	Intuitive, pointing & selection	Availability	Direct positioning device
Hands-free	Foot controls	Reduced hand mobility	Restrained seated postures	Limited research evidence
	Head controls	Upper limbs impairment	Motion range & control	Only for special needs users
	Eye-tracking	Motor control impairment	Portability, accuracy	Still in development
	Mouth controls	Severe mobility impairment	Motion range & control	Only for special needs users
	Voice input	Motor impairment	Accuracy, voice fatigue	Complement other devices
	Brain input	Severe motor impairment	Still in development	Basic research needed.

Figure 27 Best application and limitations of the most used input devices [2]

5.1 What is coming next?

Input devices are still developing around the world; here is a list of actual and futuristic input devices:

- Eye control: a good alternative to point in big screens, almost no effort, but it has (still?) not a good precision, and the cost is still too high [9];
- Brain control: perfect for almost all application, but how can it be used is still an open question, should man wear an helmet or some electrode to use this technology? This is an optimal way, but the research on this has still a lot to do;
- Touch screen: Touch screens have been developing much in the last years, in my opinion their application is good for small devices; up to a small computer. I would not recommend their use in bigger screen because it can become tiring to always move your arm along the screen, and you would often cover with your arm important information on the screen;
- Pointing with finger: This sort of "light pen evolution" is also good for wide screens, but is not as precise as other input devices, it can also be tiring to point your finger (and arm) with big screens [7];
- Mouse: good for its high precision tasks, but it is less intuitive than a touchscreen, and on big screen probably slower than other technologies, such as finger-pointing or brain control.
- Joystick it is one of the best ways to control system with many tasks and has the advantage of a "zero position". it is less precise and quickly in pointing than other input devices;
- Light pen: have disappeared in the last years, I cannot really understand why. A similar device is the touchscreen used with a pen, which can augment the precision. It also gives an alternative of writing on the paper, but to do this, the technology still has to be improved to reach a better usability (these devices need to become similar to the paper writing, at least at the beginning of their evolution).

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