Pointing Devices for Navigation in WINDOWS-based Machine-Controllers

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Abstract: Windows-orientated software systems, such as WINDOWS, OS/2, MAC OS have meanwhile become the state-of-the-art in the field of home and office computers. They considerably ease the handling of complex systems for beginners due to the utilisation of well known metaphors, such as paper basket, file, sand-glass as well as direct manipulation techniques (e.g. Drag-and-Drop). Hence it is not surprising, that these systems are also used more and more in the field of industrial applications. Unfortunately developers do not take into account several important differences between office and industrial applications. One important difference is surely the necessity for a mouse-replacement, as a standard office mouse is not applicable due to dirt and the absence of a rolling surface. This paper will describe the problem and evaluate alternative devices.

Introduction

In the past machine controllers have been built using customised hard- and software. Today the era of open controllers based on international standards in hard- and software has begun. In order to develop cost-effective solutions those standards are more and more influenced by the PC-world.

However, problems are evident, the WINDOWS-operating system and other WINDOWS-like Systems are designed to use interactive communication techniques, e.g. drag-and-drop, virtual sliders and rulers, which require a mouse or something equivalent as a pointing and navigation device.

Based on the experience with the German open CNC controller project OSA-CA/HÜMNOS (Boll et al. 1997) tests were conducted with machine operators to determine the suitability of different pointing devices like mouse, joystick, trackball, touchscreen, touchpad in industrial environments.

State-of-the-Art in Industrial Pointing Devices

A characteristic feature of Windows-systems is the direct manipulation. It enables users to operate almost entirely by means of pointing actions. Thus users get the feeling to work with real objects, which can be moved (Drag-and-Drop), reduced or increased in size. The GUI is considered as the model of a real world and designed correspondingly (Zeidler and Zellner, 1994). The precondition is the availability of a suitable pointing device, e.g. a mouse. The user clicks on the desired object with the mouse key (selection) and certain commands are executed by certain mouse actions (function activation).

However, the mouse is not always the most appropriate device to interact with computers. In industrial applications the mouse can not very often be utilised due to dirt and due to the lack of a horizontal surface for moving it. An effective utilisation of WINDOWS-systems in this field requires the development of a suitable alternative. Several alternatives have already been introduced, however, each has its advantages and disadvantages. Depending on the relation between action location and target location pointing devices for direct manipulation can be divided into direct-control and indirect-control pointing devices (Shneidermann 1997). Direct-control pointing devices enable the user to make inputs directly with the hand on the screen surface at locations where the process information is displayed. In case of indirect-control pointing devices action location and target location are separated from each other. Compared to direct-control pointing devices more cognitive processing and an increased hand-eye co-ordination is required in order to bring the onscreen cursor to the desired position. Numerous devices are available in both categories, which have specific advantages and disadvantages.

Direct-control Pointing Devices

The **lightpen** is a direct-control pointing device that was frequently utilised in the past. It enabled users to select an object directly on the screen and to perform a positioning or other task. However, users were disturbed by a cable, that was necessary to transfer the information of the selected point to the computer. Furthermore, the lightpen principle works only with CRT´s and not with LCD´s which are more and more used in industrial applications.

A technique similar to the lightpen is utilised for **touchscreens**. It allows an intuitive handling and control by the user (see-and-point). The touchscreen does not require an extra device, that must be picked up by the user, but it enables inputs directly with the finger on the screen. The disadvantages are smudging of the screen surface by finger prints especially in industrial applications (e.g. with cooling lubricant mist), and parts of the screen are obscured by the users’ hand. The input resolution is rather low due to the finger size. Hence touchscreens should only be utilised for selecting large-surface objects. The high friction between finger and touchscreen results in a good attenuation against undesired minute movements on the one hand but impedes the drag-and-drop function on the other hand. Depending on the physical principle touchscreens may not react to gloves, which must be taken into account when selecting a certain field of application.

A further limitation is the absence of the mouse-buttons. Whereas clicking and double-clicking can be realized by short finger strokes on the touch-sensitive surface, dragging while ´holding down a button´ will mandatorily require a two hand operation.

Indirect-control Pointing Devices

The device which resembles the mouse the most is the **trackball**. The trackball is also utilised in many industrial applications and enables a very exact positioning on the one hand but reacts rather sensitively to vibrations on the other hand. Hence it should not be used in mobile work places, such as train or airplane cockpits. Experiments with various designs have shown, that a **trackball** should be attenuated by e.g. felt dampers in order to avoid uncontrolled rolling after an input and to attenuate light vibrations. In comparison to the mouse the trackball does not require a lot of space. Desk space or mouse pads are not necessary.

The **touchpads** are also touch-sensitive devices. The finger movement is detected by a pressure-sensitive sensor foil. In the meantime touchpads are used extensively in laptops which has resulted in improved reliability and lower costs. Precise positioning can be achieved and touchpads are rather insensitive to dirt due to the non-existence of any open or moving components. The relatively large-surface contact between finger and foil results in a high attenuation against undesired movements. Thus touchpads are very suitable for mobile work places. (For the first time in cockpit technology touchpads are used in the Boeing 777 as an inflight input device).

The **joystick** has proved itself as a pointing device for many years and can also be found as a robust industrial design. However, experiments have shown very clearly, that it is a rather unsuitable tool for navigating on screens. Its utilisation is only recommended for moving machine axes, when the movement directions of the axes correlate with the axes of the joystick.

The **trackpoint** or **mousestick** can be considered as a miniature version of the joystick. It is a small isometric joystick (often embedded in laptop keyboards). It has a rubber tip to facilitate the finger contact and to avoid slipping. With modest practice, it can be used quickly and accurately while keeping the fingers over the keyboard. In industrial applications where the input devices are predominantly installed vertically and full keyboards are not so often used, a trackpoint has no advantages.

The **mouse-button** mainly equals the trackpoint in terms of design, but the characteristics of a button have been incorporated. It is force-sensitive and can be moved in four directions with the finger. Tests revealed that users had difficulties in getting used to this device especially while handling it vertically at the eye-level, however it is cost-effective and can be easily embedded even in sealed panels. Today, the mouse-button is already used in several industrial controllers (e.g. Allen-Bradley, DASA).

Function keys still remain the most frequent pointing device. However, their utilisation results in renouncing major advantages of Windows-systems, such as drag-and-drop. Sliders, rulers, and other formatting elements can not be used either.

In order to enable a basic navigation the alphanumeric keys are supplemented by special navigation keys, such as cursor right, left, up, down, page down, up. The navigation is limited to larger steps, e.g. one symbol or one input field. However this kind of navigation is acceptable for many applications in the field of control technique.

Unfortunately mistakes are very often made with respect to the selection and array of these keys. Hence it is very important in terms of ergonomics to group all navigation keys in one block and array them in a clear lay-out according to the rules of natural mapping. In order to reduce costs in many cases the standard alphanumeric keyboard is used to input navigation commands by simultaneously pressing several keys, e.g. Shift + Up, which is rather confusing and user-unfriendly.

Three logic levels must be distinguished for reasons of operating logic. Four directions of movement can be attributed to each level.

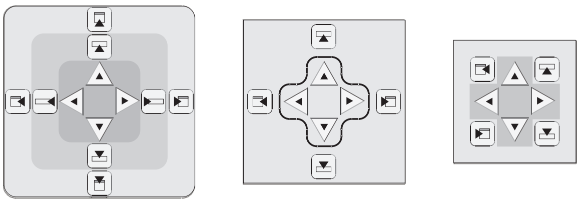

Figure 1: Array of cursor-movements

On the character-level the cursor is moved character by character, on the input field level from input field to input field and on the page or window level from page to page or from window to window. Since in many applications all four directions of movement are not required at all levels, it is possible to reduce the full arrangement shown in figure 1 left to the reduced versions displayed at the center and right.

Apart from the devices described in this study there are other devices, such as the Gyro-Mouse, the 6D-mouse, which will not be explained in detail, because their application in the field of process control has not become accepted yet.

Validation and Comparison

Influence of Operating Position

The operating position must always be taken into account before selecting a pointing device. Hence the mouse is a very suitable device while working in a sitting position at desks, however, it is absolutely inappropriate for working at vertically installed machine control panels.

Special emphasis must be put on the ergonomic requirements in the field of machine control, where panels are installed vertically and very often mounted in swivelling consoles.

The precise data input with pointing devices puts high demands on the users' fine-motoricity. These demands can only be met if on the one side the user's hand is supported (figure 2) and on the other side the pointing device is installed at an appropriate level in terms of ergonomics (mostly elbow-level).

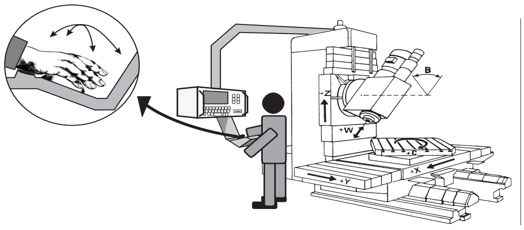

Figure 2: Ergonomic hand support at a machine controller

However, this requirement may conflict with the design of the control panel. If e.g. touchscreens are utilised an ergonomic operating position can only be achieved by installing the panel at elbow-level, but a good readability even from larger distances demands an installation at eye-level. Since both aims can not be accomplished at the same time, preference must be given to one or the other option. If the control panel is mounted in a swivelling console, any movement during operation must be impeded. Very precise pointing operations are made impossible by the slightest vibration. This especially applies to most force-sensitive industrial mouse-buttons. In order to perform very precise movements in two directions by using considerable power a wrist support and an absolutely rigid console construction are needed.

Conducted Tests

Problems with the input techniques for Windows-based software systems have only arisen recently. Therefore hardly any experience could be gained in this matter. Scientific results can only be obtained from realistic experiments with test persons. A first comparative investigation with 20 persons has been carried out at this institute and has provided some interesting results.

The test persons had to perform the following tasks:

1. Select a menu and pull-down to item

2. Click on several buttons

3. Select a large-surface window

4. Drag a rectangular to a given size and position

5. Select a text-string within a text-page

6. Track a given curve very precisely.

A computer automatically recorded in a logfile the times needed by the test person to perform the tasks as well as the error rate (Ziegler and Ilg, 1993). Hence it can be assumed that the data is complete and not influenced by any disturbing factors. Since the logfile only shows times and does not give any information about the users intentions an additional questionnaire was handed to the users. It provides a subjective evaluation of each pointing device. Questions like „Do you have any difficulty in learning to operate the pointing device“ have been asked among others. The suitability of the pointing devices for each test task was determined by a five-step ranking scale (Bortz and Döring, 1995). Impressions gained by observing personnel were recorded in an additional test protocol. The optimal operating position for each task was investigated by modifying the position of the pointing device horizontally or vertically.

As only one sample of each device was used for the first tests, the quantitatve results are not valid in generality. Comparisons with samples of different manufacturers unveiled significant differences especially for different touch technologies. Currently further tests are conducted with samples from different manufacturers to eliminate the technology influence. As most of these devices are not plug-compatible but instead require the installation of manufacturer specific drivers and a system-reboot, the tests turned out to be more time-consuming than previously expected. The latest and comprehensive quantitative values will be distributed during the conference.

Results

Table 1 shows the comparison of measured times between the different pointing devices for each task in a desk-like workplace. The measured error rates representing the accuracy of operation mostly correspond to the time values. Only for Task 6 (precise curve tracking) the error rates of touchscreen and joystick are considerably higher

Table 1: Quantitative results for each task in relation to pointing devices (mean values, horizontal)

	Task-No.					
DEVICE	1	2	3	4	5	6
	Time [s]					
MOUSE	8,3	9,6	4,6	13,6	10,5	19,8
TOUCH-SCREEN	19,9	10,0	5,0	40,5	19,7	30,0
TRACK-BALL	9,9	11,6	5,8	14,0	12,3	28,0
TOUCH-PAD	18,7	17,5	11,1	37,9	19,5	45,0
JOY-STICK	20,2	20,3	11,1	58,1	30,3	35,8

KEYS	14,5	20,8	5,5	28,8	25,5	-----

Table 2 shows the qualitative results of the evaluation. The valuation criteria in the questionnaire were general valuations and explicit subjective criteria. For example:

Soil sensitiveness (A)

Attenuation (B)

Subjective valuation (C)

Optimal operating position (D). Some devices can be used in horizontal (h) or in vertical (v) position or both (h/v).

Table 2: Qualitative valuation criteria of pointing devices

	Criteria			
DEVICE	A	B	C	D
MOUSE	**-**	**O**	+	h
TOUCH-SCREEN	**O**	+	+	h/v
TRACK-BALL	**O**	**O**	+	h/v
TOUCH-PAD	+	+	**O**	h
JOY-STICK	+	**O**	**-**	h
KEYS	+	+	**O**	h/v

In case of an appropriate object display (object size adjusted to finger size) the touch-screen proves to be very suitable for quick pointing, due to an optimal hand-eye co-ordination (selection tasks). Its operation can be learned within a relatively short time. Major disadvantages become obvious if the touchscreen is utilised for movement tasks, i.e. if an object must be moved on the screen surface, a text must be highlighted or a line must be tracked. It is also unsuitable for exact positioning like on small standard Windows-elements (Radio-buttons, check-boxes).

As a pointing device which is very similar to the mouse the trackball achieved good results. It only shows disadvantages when it comes to exact tracking, which is reasoned by the finger position. A key must be pressed with the thumb or the index finger while the remaining fingers must move the ball at the same time. Most people have difficulties in performing the exact finger co-ordination required for this task.

The touchpad also achieved good results in simple pointing tasks. However, it shows a drawback at movement tasks, when cursors must be moved while pressing the Enter-key. The human finger co-ordination is unsuitable for the unfavourable construction. The index finger is utilised to select the desired object (e.g. painter or text marker), but the object can only be activated by pressing the ENTER-key with another finger. In most cases the thumb is used for this purpose.

Joysticks are a useful tool when e.g. a moving object must be tracked on the screen, but exact positioning and selection tasks can not be performed. Due to the usual way of operating a joystick (upright with loose fist) test persons considered it as very difficult to position the cursor in a reasonable time on a desired object.

The keyboard enables to select and activate single objects in a Window-surface but impedes spatial manipulation, i.e. movement of objects on the surface. However, if the system design has been adjusted especially to keyboard interaction as in the German Open CNC Controller Project OSACA/HÜMNOS (Boll et al. 1997), the keyboard proves to be a cost-effective and reliable alternative. Various input fields (e.g. text boxes) can be selected within a window by means of the group-change keys. A window-toggle key is used to jump from one window to another and the scroll keys to scroll within data fields (Fig. 3).

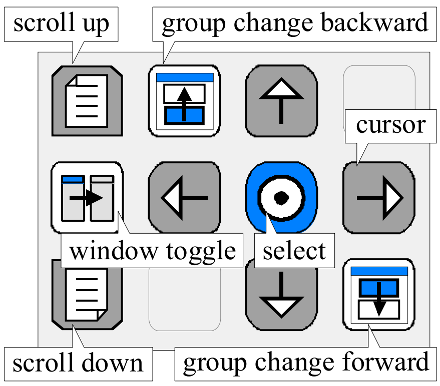

Figure 3: OSACA/HÜMNOS array of keys

Conclusion

If Windows-based systems are incorporated in the frame of the development of a new controller, a suitable navigation concept must be developed in the first place. The well-known techniques from office applications, such as mouse operation or drag-and-drop can not simply be adopted. The mere utilisation of a keyboard meets the industrial standard, but many advantages of modern software systems can not be made use of. New developments in the field of control technique will demand new solutions in the interaction with users. This study may facilitate to select an appropriate device. Further investigations need to follow resulting in concrete design guidelines for developers of control techniques. A final decision should only be taken after comparative tests with several test persons have been carried out under realistic process conditions.

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