ERGONOMIC DESIGN OF GRAPHICAL CONTROL ELEMENTS ON PRODUCTION MACHINES

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Abstract
The trend of increasing technological complexity of machines mainly correlates with the integration of additional functions in machines. Increasing functionality of the machines leads to an increased number of control elements, which limits the clarity of the machine operation and leads to higher cognitive demands in the machine operation.
Due to the growing functional range of production machines the demand of usability for the operating systems continues to grow. The selection and design of icons for the identification of controls contributes significantly to usability, especially for intuitive operation of production machines.
The aim of this study is to investigate the intuitive usability of production machines, to consider its use of graphical elements (icons) and to derive recommendations for a demand-oriented selection and design of icons. To achieve this goal, laboratory studies at five modern production machines (laser sintering machine, CNC universal lathe, plastic injection molding machine, laser processing machine, woodworking machine) - each with different operating concept - were performed.
The results of the study show that the used symbols in the examined machines are only limited self-explanatory and intuitive, and thus have significant deficits for easy and intuitive operation. Especially the combination of screens and electronic keys or switches was often criticized and leads to uncertainty in the operation. As a result, recommendations for the design of icons on production machines are given.

Keywords:
Usability, production machines, icons, usability, human-machine compatibility

1 BACKGROUND TO THE STUDY

The ergonomics of production machinery is becoming increasingly important, particularly in the context of Industry 4.0. The trend towards ever-increasing technological complexity and greater functional scope in machinery is accompanied by a greater number of operating elements, which in many cases limit the clarity of operation [1] and lead to greater cognitive demand during the operation of machinery [2]. As a consequence, there are increasing requirements with regard to the usability of the operating system.

Graphical user interfaces on screens and symbols should assist the user in operating machinery and provide information independent of language [3]. The symbolic identification of operating elements clearly aids usability, particularly in terms of the intuitive operability of machinery.
It should be noted that understanding of icons inevitably changes over time [4] and may not be self-explanatory to the same degree for different target and age groups. An examination of icons on the operating interfaces of production machinery reveals that they have not been further developed with any urgency in the last ten years, as they have for example in smartphones or in the field of IT [1].
However, in practice, another challenge is posed by the fact that unskilled workers both at home and abroad are employed to operate production machinery, leading to increased difficulties in the interpretation of the icons used. A further complicating factor is that the ability of foreign workers to read cannot always be assumed, leading to an additional requirement to use only clear, self-explanatory icons.
International standard DIN ISO 7000:2008 provides an overview of more than 2,500 icons for technical equipment [3]. In the production machinery investigated in this study, only a small proportion of standardized symbols were identified. The majority of the symbols were designed by the machinery manufacturer.

2 APPROACH AND METHOD

In view of the problem as described, this study investigates the intuitive operability of production machines and their operating systems in respect of the icons used, and derives recommendations for action which will lead firstly to the user-friendly design of machine operating systems (user interfaces) and secondly to increased productivity. Another important aspect of improved usability is a reduction in training and teaching expenditure and increased acceptance of new machines and technologies by machine operators.
The investigation as carried out is divided into three case studies. The case studies include laboratory and field investigations on five modern production machines (laser sintering machine, CNC universal lathe, plastic injection molding machine, laser processing machine, woodworking machine), each with a different operating concept (Fig. 1).

Case study	Production machine	Year of manufacture	Operating system	Number of test subjects
1	Laser sintering machine EOS FORMIGA P100 and P110	2006/2011	Display with touchscreen	11
2	CNC universal lathe DMG MORI SEIKI CTX alpha 300	2013	Button operation and graphic display	10
	Plastic injection molding machine Arburg Allrounder 420 C	2008	Button operation and graphic display with touchscreen	10
	Laser processing machine Laservorm LVS-909F	2011	Button operation and graphic display	10
3	Woodworking machine	2013	Button operation and graphic display with touchscreen	11

Figure 1: Information on the production machines investigated

The first case study was conducted as a laboratory and field investigation at a major manufacturer of industrial joining technology as well as in the laboratory for development and design of the Ostwestfalen-Lippe University of Applied Science. In the second case study, usability tests were conducted in various laboratories at the Ostwestfalen-Lippe University of Applied Science. Case study 3 was conducted at a manufacturer of woodworking machines and two other production facilities in the timber industry.
The selected approach in all case studies included the conduct of usability tests in combination with video and speech recordings, the use of questionnaires and a final workshop in which measures were discussed and design recommendations extrapolated on the basis of the results of the analysis.
For the usability tests, test subjects were recruited from students and academic staff of various ages at the University of Applied Sciences Ostwestfalen-Lippe without any previous experience with the production machine in question. The test subjects received a short introduction to the production machine in question and were required to complete and comment on various tasks with minimal assistance from the investigator. Fig. 2 shows a section of the usability test at the CNC universal lathe.

Figure 2: Usability test at the CNC universal lathe

After all tasks had been concluded, a questionnaire – based on the Compendium of Ergonomics from the Federal Institute for Occupational Health and Safety [5] and the software questionnaire ISONORM 9241/110-S /ISONORM 9241/10 [6] – was completed on the operation of the machine, in which various aspects of the operation and design of the production machine were evaluated.
In addition to basic functions - such as switching the machine on and off - tasks on the production machinery included a selection of typical work tasks carried out by machine operators during normal use. Each usability test lasted approximately 45 minutes per test subject.

3 RESULTS OF THE INVESTIGATION

The evaluation of the recordings and videos from the usability tests show that the human-machine compatibility of the production machinery investigated in terms of the intuitiveness of the icons used could be improved.
In carrying out the tasks, so-called errors were frequently observed, the cause of which could be traced back to unsuitable representation of icons or their captions. Fig. 3 shows the errors observed, the nature of the errors and the

causes identified. Thereafter a selection of examples of the errors observed is reproduced.

Actions (errors) observed	Type of action (error)		Root causes
Icon not found	Icons	Function of the icon not interpreted	Icon representation not comprehensible
		Icon assumed to be at another position	Unexpected arrangement
	Icon caption	Icon caption not legible	Incomprehensible abbreviation or writing too small
		Icon caption not comprehensible or not as expected	Imprecise, non-attributable choice of term or incomprehensible language
Operating error	Icons	Icon confused with another	Insufficient differentiation
			Representation in the wrong context
Additional and superfluous actions	Icons	Multiple choice or search for additional icons	Missing feedback on action
		Uncertainty and search for possible subsequent steps	Color representation or change of color not as expected

Figure 3: Errors observed and root causes

1. Icon not found

For example, on the laser sintering machine, difficulties were observed among the test subjects in loading the construction task (7 of 11 test subjects), as the icon representation was not perceived as comprehensible and was criticized [7]. On the CNC universal lathe, icon no. 0983 with the title "Program with machine function" (cf. [3]) was criticized by virtually all test subjects (9 of 10 test subjects) as not being self-explanatory, as it could only be found on the basis of its caption. On the woodworking machine, 7 of 11 test subjects could not find the icon to switch on the heating, as the abbreviated term "Auftragsei..." (german) could not be interpreted and the icon representation was not self-explanatory.

2. Operating error

On the CNC universal lathe, all test subjects used the "SELECT" button to select a program, despite the fact that this button was not relevant in this context. On the woodworking machine, six of the eight main function icons were either not recognized by the test subjects or were associated with other functions and selected accordingly.

3. Additional and superfluous actions

On the woodworking machine, for example, it was not clear to several test subjects whether a unit required for a particular process was switched on, as the yellow representation of the icon did not conform to the test subjects' expectations and was associated with an error. All 11 test subjects failed in the task of feeding in material for the process, as simply pressing the icon did not bring any response from the system or an instruction. Both mentioned examples led to uncertainty among the test subjects and a search for possible subsequent steps.
Overall, it was determined in the context of the whole study that self-designed icons appeared not to have been tested sufficiently or at all by the machine manufacturer during the development phase of the machine, and there were obvious weaknesses in the intuitiveness of individual icons. In addition, the results revealed that the use of standardized icons from DIN ISO 7000:2008 may be problematic, as the icon representations were not consistently perceived as intuitive by the test subjects. The errors set out in Fig. 3 could significantly slow down operation, lead to operating errors and cause uncertainty in the operator.

4 REQUIREMENTS FOR THE DESIGN OF ICONS

In designing icons, recommendations for software ergonomic design should be taken into account. The basic principles of dialog design for human-system

interaction set out in DIN EN ISO 9241-110 - such as suitability for the task, intuitiveness and conformity to user expectations - can be applied to the design of icons. The multi-part DIN EN 80416 series of standards provides general principles and rules for the design of icons on machinery and equipment which also help icons to remain identifiable when they are greatly reduced in size during use [8].
Taken as a whole, these standards and series of standards require icons to be quickly and unambiguously identifiable, recognizable independent of language and culture, distinctively designed and compliant with the standards (e.g. icon in the form of a diskette for the "save" function). Feedback from actions is important for the operator to identify the current processing progress, and to enable further actions to be extrapolated [9]. An appropriate color scheme assists in triggering the correct action in the operator. Icon captions must be designed to be comprehensible and easily legible to provide additional assistance in identifying the icon.
In addition, it should be noted that the intuitiveness of an icon can also be improved if it is only offered in a specific context [4]. With situation-based decision support, quick and reliable task processing can also be achieved [10].
Finally, it is recommended to test graphical operating elements in accordance with DIN EN ISO 9241-210:2011 during the development process of the machines.

5 CRITICAL EVALUATION

The results show that clear weaknesses exist in the intuitiveness of individual icons and that there is a potential for improvement in the intuitive operation of production machinery. The errors set out in Fig. 3 could significantly slow down operation, lead to operating errors and cause uncertainty in the operator.
Overall it may be noted that the improvement of the intuitiveness of icons can make a clear contribution to improving the user-friendliness of production machinery, reducing the training and teaching expenditure and increasing the acceptance of these machines and technologies. The research methodology may be criticized for the fact that the test subjects came from only one cultural background and had a high level of education. However the production machinery investigated are occasionally operated in newly-industrialized countries by personnel who have a very low level of education. In addition, only a selection of the icons on the production machinery were investigated, so it may be assumed that there is further potential for improvement on these machines.
Further investigation with different groups of people and additional icons is recommended. Further findings could mean that a generally-applicable icon for a specific function cannot be designed, but that various cultural groups must be offered different symbol systems [11].

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