VISOR – Towards a Three-dimensional Shop Floor Visualisation

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ABSTRACT

A key objective in designing human-computer interfaces in the field of industrial manufacturing should be the dynamic visualisation of manufacturing processes with help of innovative visualisation elements. This article describes a comparative evaluation study of two ways of visualising complex shop floor activities in real-time: a traditional two-dimensional, windows-based form of visualisation and an innovative three-dimensional, realistic interface, the so-called Virtual Shop Floor (*VISOR*). In order to evaluate both visualisations, an experimental investigation with 20 test persons and the application of different evaluation methods (eye mark registration, key stroke recording, video-taped observation and interviews) was performed at the ifab-Institute of the University of Karlsruhe. One result of this investigation shows, that the cognitive strain of the test person is high-significantly lower when using the realistic interface in comparison with the traditional visualisation.

1. INTRODUCTION

In spite of long-lasting scientific research concerning the usability-friendliness of human-computer interfaces, there is still a lack of cognitively-orientated experimental investigations of realistic visualisation techniques in the field of industrial manufacturing. Many large research projects have addressed the issue of human-computer interaction in the office, but only a few consider the dynamic nature of processes (Fleischer & Becker, 2000, p. 7), especially in manufacturing systems which are structured as shop floor systems. Such human-computer interfaces should support the workers in performing operative tasks like observation and monitoring of shop floor processes, checking the conditions of machines and tools, assigning materials to orders, tracing breakdowns and so on (REFA, 1991, p. 388). According to Wickens and Hollands (2000, p. 513), the supervision of such complex processes incorporates detection, perception, attention, diagnosis, communications, memory, decision making, and action selection.

In contrast to designing human-computer interfaces for offices, some specific requirements have to be met when developing interfaces for manufacturing: transparency of dynamic shop floor processes, real-time observations and interventions, availability of historic data should be regarded predominantly. Therefore, the shop floor information (e.g. manufacturing state of orders, conditions of machines, quantities of materials, applied tools and NC-programmes) has to be presented to the workers in a comprehensive, actual, process-oriented, perceptible, interpretable and user-friendly way in order to fulfil the transparency requirement.

2. CONCEPTION OF *VISOR*

The ifab-Institute of Human and Industrial Engineering at the University of Karlsruhe is occupied with the structured development and the cognitively-orientated experimental evaluation of user interfaces for the shop floor. Two process-oriented human-computer interfaces supporting the shop floor workers are the basis for the recently performed comparative investigation: a traditional two-dimensional, standard windows-technique based visualisation and an innovative three-dimensional, realistic interface, the so-called Virtual Shop Floor (*VISOR*).

2.1 Applied cognitive psychology models

A user-friendly design of human-computer interfaces for the shop floor requires an integration of human information processing aspects. Therefore, the use of computer-supported shop floor systems calls for a mental-compatible representation of the shop floor. Accordingly, it seems to be relevant to consider cognitive psychology models and the mental abilities of the user. The design of these visualisation techniques takes perceptual psychology models, e.g. mental models (Johnson-Laird 1983; Dutke, 1994, p. 77) or the mental activity model (Rasmussen, 1983, p. 257; Rasmussen, 1986, p. 99), into consideration.

2.2 Presentation of *VISOR*

The main component of *VISOR* is a three-dimensional shop floor model reflecting the user's point of view, which consists of realistic objects like machines, tools, materials, but also of abstract objects, such as orders, timetables and so on (figure 1). The shop floor worker gets a great deal of information directly from the objects it is assigned to (e.g. information about machines). Consequently, most of this information should be displayed on the screen at the same location in which the related object is situated in reality.
This information collecting approach is implemented in *VISOR*. Thus, the user knows exactly where the information originates and can navigate and explore the *VISOR* environment in order to take up the necessary information for carrying out operative tasks. Graphics, photos or multimedia, dynamic visualisation elements are used for showing actual process conditions. For example, manufacturing processes and machine operations can be supervised with the help of dynamic video sequences (figure 1).
Abstract information bases (like orders) are transformed into realistic objects and are assigned to *VISOR* shop floor items. For example, orders are equated with skeleton boxes. Therefore, the worker is able to discover information about orders (such as actual state of a manufacturing order, processing time, adherence to schedule) in the skeleton box representing this specific order. Additional abstract information which the worker needs and which is not obviously assignable to a "real" object (e.g. general internal announcements) is presented as a notice on special black boards.

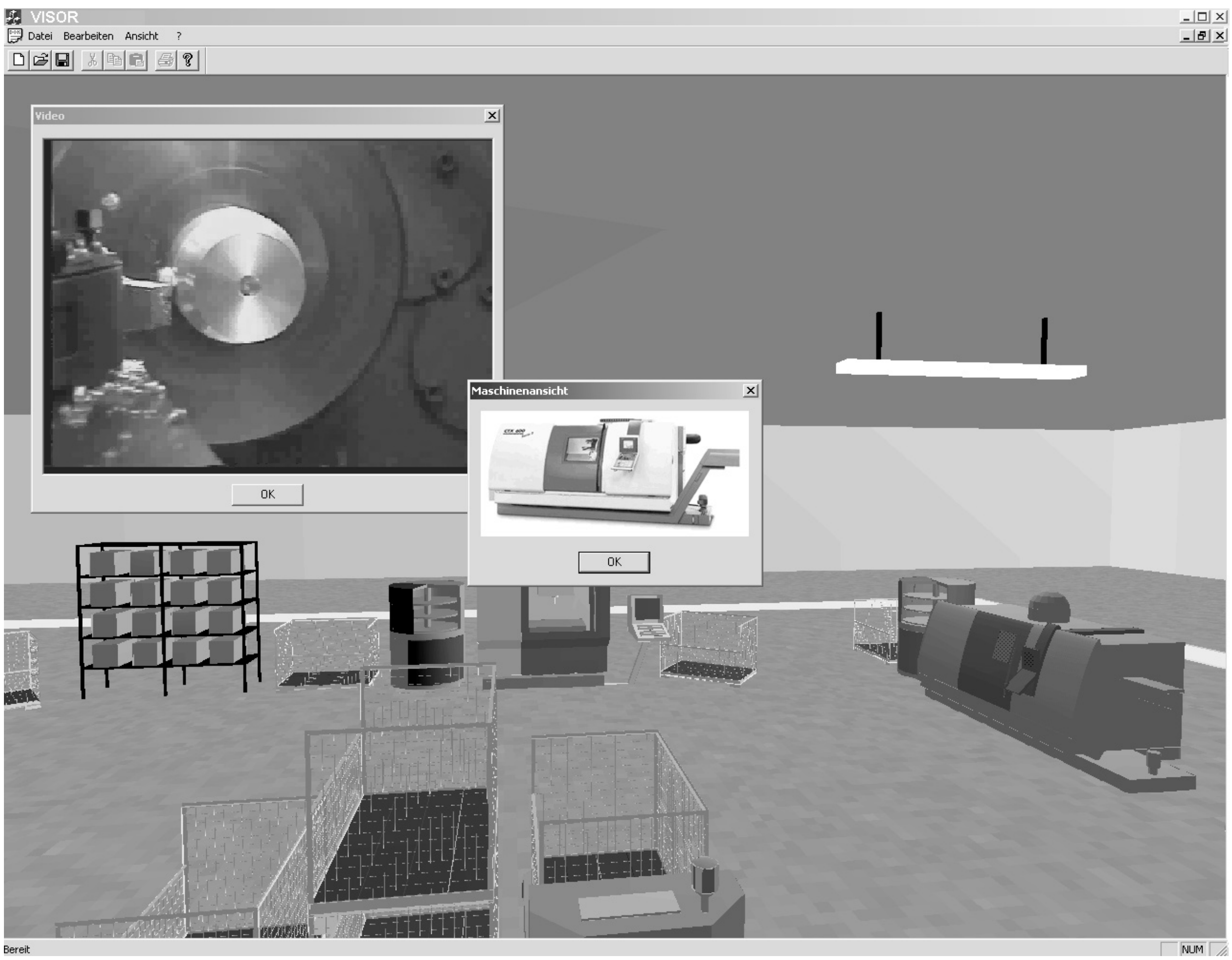

Figure 1: Three-dimensional visualisation of the shop floor with *VISOR*

To ensure correctly performed shop floor processes, mental-compatible mechanisms for tracing breakdowns have been integrated. For example, after recognizing a breakdown by the computer system, an object-oriented alarm will be triggered and the breakdown will be recorded. For that purpose, *VISOR* distinguishes between several machine running states and codes them differently: "running" (green light), "standstill" (yellow light), "breakdown" (red flashed light), "maintenance" (blue light).

3. COGNITIVELY-ORIENTATED INVESTIGATION OF TWO FORMS OF VISUALISATION

Both realised human-computer interfaces were investigated in comprehensive experiments at the "Laboratory for Human-Machine-Interaction" of the ifab-Institute (see for details Stowasser 2001). In the experimental study 20 test subjects were included, from which 10 were academic students and 10 were industrial shop floor experts.

3.1 Hypotheses of the evaluation study

The goal of the investigation was to determine practical design aspects for the use of two- or three-dimensional visualisation techniques on the shop floor. Basically, two hypotheses were followed by the comparative evaluation study. Hypothesis 1 investigated the statement, that the three-dimensional, realistic interface represents the mental models of the users more suitable than the two-dimensional, windows-based visualisation form. Hypothesis 2 followed the assumption, that the suitability of both visualisation forms depends on the complexity of the operating tasks. Therefore, the study helped to sort out specific situations on the shop floor in which a specific visualisation technique is most helpful.

3.2 Experimental methods

In order to achieve the results, several evaluation techniques were used: eye mark registration, key stroke recording, video-taped observation of the test person, interview with checklists. The eye mark registration with a "SMI Head-mounted Eyetracking Device System" (SMI 1999), for example, is very useful in finding out which spot on the interface the user is looking at, which type of information representation he prefers or, generally speaking, in which way the cognitive information processing is proceeding. Both the visual field and the fixation points can be observed on a television monitor and can be recorded with a video recorder. In particular, dependent variables like fixation-derived numbers (number and duration of fixation) and saccadic-derived numbers (saccadic extent, saccadic velocity, saccadic acceleration) give objective hints on aspects of a user-friendly visualisation. Key stroke recording was used to examine interactions of the test persons and to record e.g. the time the user needed to perform a specific task. Furthermore, other methods, such as video recordings of the test person´s actions and structured interviews, were used to obtain subjective information.

3.3 Investigated shop floor tasks

Basis of the investigation were scenarios with typical tasks of controlling shop floor processes. Each test person had to deal with six scenarios differing in the form of visualisation (two- or three-dimensional) and the complexity of the tasks. The complexity was varied by varying the number of visualisation objects (machines, orders) and the kind of tasks in each scenario (rush orders, unforeseen events). Examples of characteristic tasks are: "Check the quality of the manufactured items of orders 4 and 7", "Control the state of the manufacturing order 5", "trace the reason for the breakdown of lathe 1" (unforeseen event), "assign order 3 to lathe 2" and so on.

4. RESULTS OF THE EVALUATION STUDY

4.1 Eye mark-oriented results

A mulitvariate analysis of variance (MANOVA) and several univariate analyses of variance (ANOVA) of the dependent variables show, that numerous eye mark variables are high-significantly dependent upon the form of shop floor visualising. The duration of fixation is probably the most frequently used variable in assessing the human information process. Generally spoken, this variable is strongly influenced by the cognitive processes, which are necessary to perceive and process the presented information. According to Rötting (1999, p. 8) the cognitive information processing velocity is reflected in the fixation duration.

The average duration of fixation of the test persons, which is high-significantly dependent upon the form of visualisation (F=131,5; df=1; p=.000 < a=.01), differs between 330 ms (two-dimensional) and 256 ms (three-dimensional). Interpreting the average duration of fixation leads to the conclusion, that the cognitive strain of the user is lower when using the three-dimensional, realistic shop floor visualisation of *VISOR*. The increase in the average duration of fixation when using the two-dimensional visualisation results, according to Unema (1995, p. 161), from the increase in necessary cognitive performances due to lower compatibility of the shop floor visualisation with the user's mental model.
Another variable of the eye mark registration is the duration of initial fixation. Initial fixations characterise the first cognitive access to a novel scene and the orientation time of the user. The investigation shows, that the average duration of initial fixation is high-significantly smaller when using the realistic shop floor visualisation (F=10,7; df=1; p=.001 < a=.01) than when using the traditional windows technique. Obviously, users can recognise the dynamic changing situations on the shop floor faster when using a realistic form of information visualisation.

4.2 Processing time

On average, the users needed approximately 35 minutes to process all scenarios. The total processing time is high-significantly dependent upon the complexity (F=815,8; df=2; p=.000 < a=.01) and the form of visualisation (F=8,2; df=1; p=.005 < a=.01). Significant interactions between these effects are not recognisable (F=0,1; df=2; p=.884 > a=.05). The Box-and-Whisker plot in figure 2 illustrates this fact: the average processing time increases with increasing complexity. Within the complexity levels, the average processing times are tendentiously shorter when using *VISOR*.

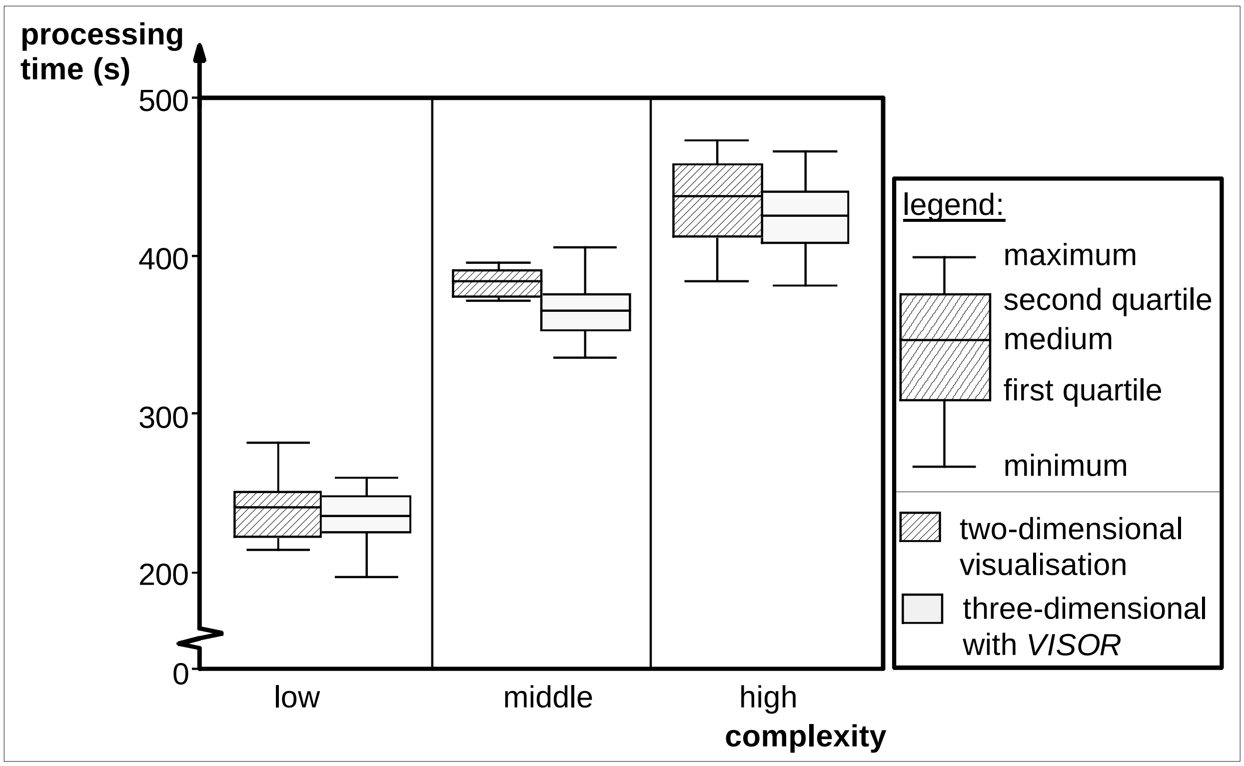

Figure 2: Processing time depending on form of visualisation and task complexity

4.3 Subjective statements of the users

After performing the scenarios, the test persons rated their perceived strain with help of a five-level scale (no, low, middle, strong, very strong strain). The applied Kruskal-Wallis-Test shows, that the subjectively perceived strain of the test persons depends significantly (?²=5,2; df=1; p=.023 < a=.05) on the used form of visualisation. On average,

over all persons and scenarios, the test persons felt a middle strain when using the traditional representation and a low strain level when using the realistic form of shop floor visualisation.
Moreover, it can be proved that the visualisation preferences of the users depend on the specific shop floor task to be solved. The windows-based visualisation is preferred for tasks such as like searching of data-oriented information (e.g. customer data, information of a specific order) or managerial decision and planning tasks (cf. Zülch, Stowasser, & Keller 2001). In contrast, the realistic shop floor visualisation is favoured for the performance of real-time control tasks (supervising machines), breakdown recognition tasks or in the observation of the order manufacturing process.

5. CONCLUSION

The three-dimensional realistic forms of visualisation (e.g. *VISOR*) offer new opportunities for human-computer interfaces in manufacturing systems, especially for the support of real-time operative tasks. The three-dimensional human-computer interface gives the workers, in many cases, easier access to information as it is the case with traditional window interfaces (e.g. overview of dynamics and structures of the shop floor, error removal). It capitalises on the typical cognitive aspects of human perception and information processing by adapting the human-computer interface to the mental models of the user on the shop floor. Such innovative human-computer interfaces provide features, information and structures that a user might explore in a cognitive semantic way.

REFERENCES

Dutke, S. (1994). Mentale Modelle. Göttingen, Stuttgart: Verlag für Angewandte Psychologie.

Fleischer, A. G., & Becker, G. (2000). Interaktionsgestaltung bei der Kontrolle dynamischer Prozesse. Bremerhaven: Wirtschaftsverlag NW.

Johnson-Laird, P. N. (1983). Mental Models. Cambridge: Cambridge University Press.

Rasmussen, J. (1983). Skills, rules, knowledge: signals, signs, and symbols and other distinctions in human performance models. IEEE Transactions on Systems, Man, and Cybernetics, SMC-13 (3), 257-267.

Rasmussen, J. (1986). Information Processing and Human-Machine Interaction. New York, Amsterdam, London: North-Holland. (North-Hollands series in system science and engineering, vol. 12)

REFA – Verband für Arbeitsstudien und Betriebsorganisation (Ed.). (1991). Planung und Steuerung, Teil 3. Munich: Carl Hanser. (Methodenlehre der Betriebsorganisation)

Rötting, M. (1999). Typen und Parameter von Augenbewegungen. In M. Rötting & K. Seifert (Eds.), Blickbewegungen in der Mensch-Maschine-Systemtechnik (pp. 1-18). Sinzheim: Pro Universitate. (ZMMS-Spektrum, Band 8)

SMI (Ed.). (1999). iView. Teltow: SensoMotoric Instruments.

Stowasser, S. (2001). Vergleichende Evaluation zwei- und dreidimensionaler Visualisierungen zur operativen Werkstattsteuerung mit Hilfe der Blickregistrierung. Aix-la-Chapelle: Shaker. – To appear – (ifab-Forschungsberichte aus dem Institut für Arbeitswissenschaft und Betriebsorganisation der Universität Karlsruhe)

Unema, P. (1995). Eye movement and mental effort. Aix-la-Chapelle: Shaker. (Berichte aus der Psychologie)

Wickens, C. D., & Hollands, J. G. (2000). Engineering Psychology and Human Performance. Upper Saddle River NJ: Prentice-Hall.

Zülch, G., Stowasser, S., & Keller, V. (2001). Sichtenkonzept zur kommunikationsergonomischen Darstellung von objektorientierten Unternehmensdaten. Zeitschrift für Arbeitswissenschaft, 55 (2). – To appear –