Unusual, Usable or even Useful? Examining the Potential of Usability Guidelines for Industrial Interface Design in the field of Automated Guided Vehicles

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Abstract: Although automated guided vehicles (AGVs) are automated, they still require user interfaces (UI) for monitoring and, in the event of system malfunctions, for controlling tasks. To keep training and familiarization times with such UIs short, a self-explanatory design is necessary. Surprisingly however, applicability of general usability design guidelines in this context has not yet been explored. In a laboratory study, 20 participants performed tasks on two graphical UIs, one based on technical requirements, the other based on UI guidelines. Objective measures of performance, perceived usability, and think-aloud method were used. The guideline-based UI resulted in both lower task completion times and erroneous clicks, and higher perceived usability and satisfaction. Specific recommendations for AGV-UI and general UI design are presented in the conclusion of this paper.

Key words: usability, interface design, automated guided vehicle, AGV

1. Motivation

The use of automated guided vehicles (AGVs) has many advantages over conventional transport systems. AGVs enable the optimization of processes as well as the reduction of production costs. Due to controllable transport processes as well as high transparency and traceability, overall logistics becomes more efficient. A simulation study showed that the use of AGVs can save up to 22% of order processing time (Schwarz et al. 2013). Reduced staff deployment in transport can minimize labour costs, especially in multi-shift operations. In a survey of companies using AGVs, 85% of interviewees stated that reducing personnel costs was the greatest benefit of using AGVs (Clauer & Fottner 2019). Now while automated systems are designed to run with minimal human interference, system management still requires a human machine interface or user interface (UI). System management includes set up and monitoring tasks as well as navigation of AGVs and systems' errors in case of malfunctions. Takeovers of AGVs by operators is to a majority required in abnormal conditions. As these occur at irregular and unexpected intervals, operators may not be able to build necessary problem-solving skills. To address this problem, the cognitive skills, e.g., long-term knowledge in problem solving, should be supported by the UIs themselves (Bainbridge 1983). To further reduce the cognitive load within the interaction, UIs need to have high standards regarding usability to enable a fast and correct control. To ensure these high standards usability engineering and guidelines need to be applied. While usability guidelines are constantly applied in consumer products, the industrial context is often ignored, as interfaces are mostly used by experts. Therefore, this study will examine the question on how industrial UI design according to general usability design guidelines can affect performance and perceived usability for controlling AGVs.

2. Methodology

2.1 Apparatus

The AGV ‘MULI’ is characterized as an industrial indoor robotic system that can be used in a variety of applications, but typically for transportation of materials in industrial buildings. The system can use wired, vision based or laser target navigation to move around and to avoid collisions with workers or infrastructure. Regarding system management and control, MULI is equipped with two emergency stop switches on the hardware level. On the software level, MULI can be controlled by a dedicated Node-RED-based application via portable devices or a personal computer (see Figure 1). Typical system management activities are direct steering control in case of a stuck robot, overview of system status, last scanned barcodes, a battery indicator, and feedback on whether the emergency stop is activated or not.

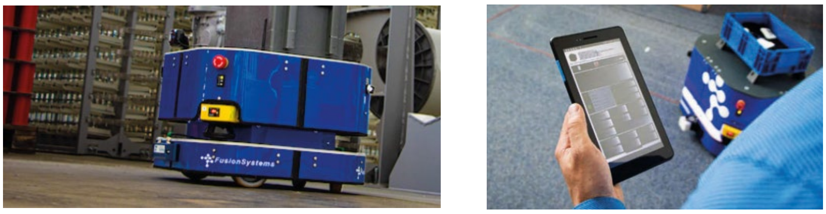

***Figure 1**:* *a) The MULI – indoor AGV from FusionSystems GmbH and b) picture of UI on a tablet for controlling the MULI. Source: FusionSystems*

The initial UI for the system management of the MULI was a basic functional UI (fUI). It was developed during the early stages of system construction but already contained all targeted functions for the final product.

During further development, the UI was revised using the Nielsen heuristics (Nielsen & Molich 1990). The goal was to develop a user-friendly UI, in scope of this research a guideline-based UI (gbUI). The adaptation targeted to minimize cognitive effort when using the system, especially for non-trained users, as a direct interaction with the AGV is, in most cases, unplanned and rather seldom. Focus of the overhaul was therefore on improving i) visibility of system status ii) error prevention iii) recognition rather than recall as well as iv) helping users recognize, diagnose, and recover from errors. Both UIs are shown in Figure 2.

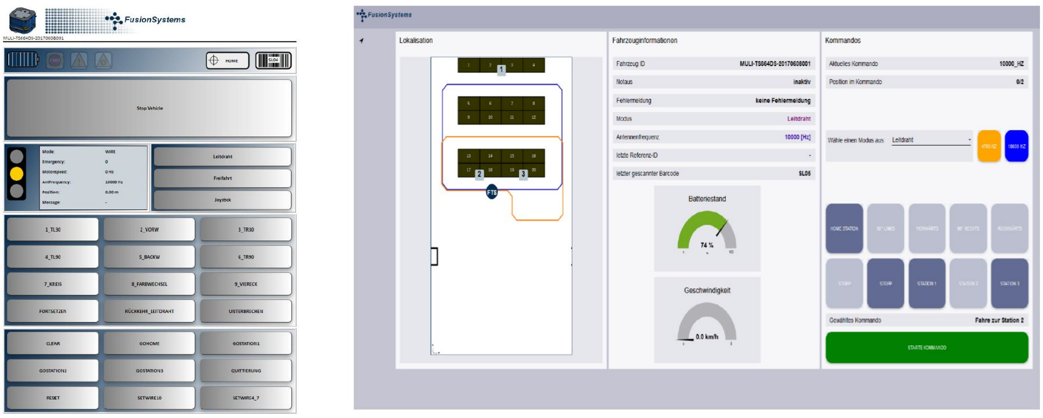

***Figure 2**:* *Comparison of applied a) functional and b) guideline-based UI. Source: FusionSystems*

2.2 Design, Measurements and Procedure

To examine the improvements in usability between both UIs, a within-subject design was applied. All participants were randomly assigned to their respective first test condition functional UI (fUI) or guideline-based UI (gbUI). Both conditions contained three identical experimental tasks in a fixed order with increasing cognitive demands. Task 1 was a combined navigation and transportation task (necessary user entries: 11 with fUI and 7 with gbUI). Task 2 additionally contained the search for requested information displayed on the GUI, e.g., reading out last scanned bar code of components or maximum speed of the AGV (necessary user entries: 13 with fUI and 9 with gbUI). Task 3 again contained navigation and transportation expanded by processing and acknowledging system error messages, here a missing hardware joystick to fulfil the working task (necessary user entries: 12 with fUI and 8 with gbUI).

Regarding measurements, demographic variables age, sex, and current profession as well as affinity for technology (ATI; Wessel et al. 2019; scale range 1 to 7, $\alpha = .85$) were assessed. Objective measurements were based on the screen recordings during interaction. *Effectiveness* was operationalized by task completion rate and e*fficiency* by erroneous clicks as well as task completion time. After-Scenario-Questionnaire (ASQ; scale range 1 to 7; Lewis 1991; German translation from Luca 2011, $\alpha > .73$) was applied to quantify subjective satisfaction with task performance after each task and System Usability Scale (SUS; Brooke 1996; German translation Thielsch 2017, $\alpha > .95$) was applied twice after completing all three tasks with one UI to quantify perceived usability. Additionally, during the interaction with the AGV continuous subjective statements were assessed using the think-aloud method.

The test procedure started with the assessment of the demographic data and affinity for technology, followed by a general instruction for AGV controlling and the think-aloud method. The AGV was positioned in a warehouse while participants controlled the system via UI on a desktop screen in another room. Participants could observe the real time control inputs of the MULI on a map. With the specific UI assigned, all tasks were performed in fixed order, each paused by the ASQ questionnaire. Participants were encouraged to speak their thoughts aloud during the session. At the end of the first condition, the applied UI was evaluated using the SUS questionnaire. The second test condition was repeated identically. In the end, qualitative feedback was collected by open questions and recalling the think-aloud protocol with the participant.

2.3 Sample and Data Analysis

20 participants (9 male, 11 female) were part of the experiment involving eight employees of FusionSystems GmbH. Twelve university students completed the sample. All subjects had no prior experience with the AGV. Median age was 24.5 years (MAD = 3.71). The sample had a medium affinity for technology ($Mdn = 4.38$, $MAD = 0.56$). Randomized sampling resulted in two equally sized groups that did not differ in age ($Mdn_{fUI} = 24.5$, $Mdn_{gbUI} = 26.0$, $W = 59$, $p = .516$) or affinity for technology ($Mdn_{fUI} = 4.63$, $Mdn_{gbUI} = 4.25$, $W = 58$, $p = .568$). For data analysis, statistics software R (R Core Team 2019) was used. Due to sample size and value distributions, nonparametric tests were applied. The nonparametric effect size r was calculated according to Tomczak and Tomczak (2014). Additionally, a randomization test (Pospeschill & Siegel 2018) was implemented to allow between-subject comparisons despite small sample sizes to evaluate the effect of initial contact with each GUI.

3. Results

To report the objective performance, completion time and rate were investigated. As identical tasks were performed with both UIs, interindividual completion rate was analysed for first contact. In the group starting with the fUI, 5 out of 30 tasks (17 %) were not completed successfully. The group starting with the gbUI could not complete 2 out of 30 tasks (7 %). For overall task completion time, intraindividual comparison revealed significant lower durations for the gbUI with a median time difference of 2.54 minutes ($Z = -4.20$, $p < .001$, $r = .939$; see Figure 3a). Relative to necessary clicks, erroneous clicks occurred in 4.58 % with the fUI but only in 0.55% with the gbUI. Interindividual comparison across tasks revealed significant less relative erroneous clicks with the gbUI ($Z = -3.17$, $p = .001$, $r = .709$). Figure 3b additionally visualizes the relative proportion of erroneous clicks dependent on UI and the specific task.

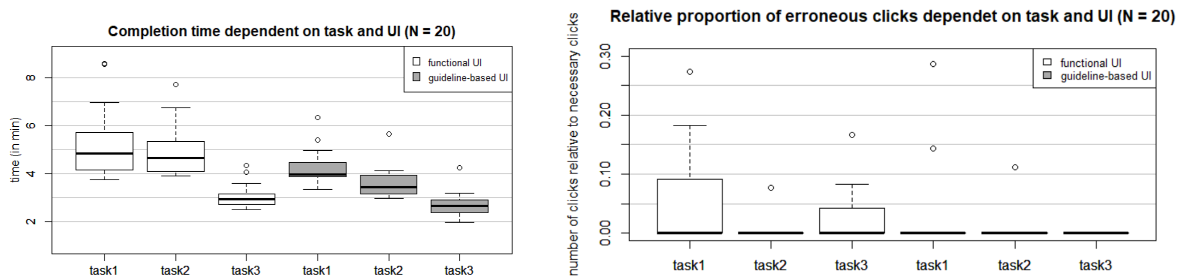

***Figure 3**: Comparison of objective performance by a) completion time and b) relative proportion of erroneous clicks dependent on task for functional and guideline-based UI.*

Regarding the subjective evaluation based on the intraindividual comparison, the gbUI resulted in significant higher subjective usability ($Z = -3.90$, $p < .001$, $r = .872$) and significant higher satisfaction ($Z = -3.50$, $p < .001$, $r = .783$) compared to the fUI (see Figure 4a and 4b). Figure 4c also visualizes the interindividual comparison for the first contact with each UI. For the fUI-condition, a small increase of satisfaction is visible in progression of tasks. This trend is not visible in the gbUI-condition due to ground effect. Randomization test revealed a significant higher satisfaction with gbUI in all tasks ($p < .001$).

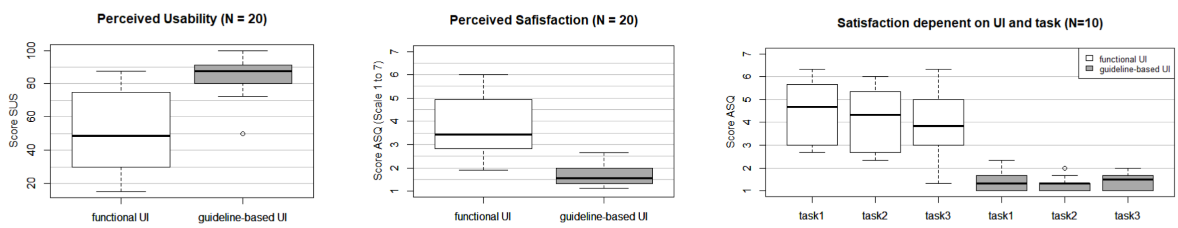

***Figure 4**: Comparison of a) usability b) overall satisfaction and c) interindividual satisfaction dependent on task and UI. For ASQ, lower values are showing higher satisfaction.*

The qualitative results of the think-aloud method showed that all 20 participants preferred the gbUI. This overall evaluation was supported by specified statements in comparison of the gbUI to the fUI, summarized in Table1. It also aggregates mentioned further existing problems and possible design solutions.

Table 1: *Advantages of guideline-based UI in comparison to functional UI and further specified potentials for improvement (also see Figure 2b for comparison)*

Number of mentions	Mentioned feature
	Advantages of guideline-based UI (gbUI)
15	Clear presentation of information
9	Irrelevant buttons were greyed out to prevent erroneous actions
6	Usage of colour coding for different navigation routes
5	Intuitive design
5	Modern and attractive design
	Potentials for improvement of guideline-based UI (gbUI)
9	Implementation of a progress bar to quickly identify current state
4	Instead of mouseover for information retrieval, use a direct labelling of the button with the needed information
3	Use equal design for all action buttons differing from design of mere information boxes
3	Visualization of effective button clicks by colour change

4. Discussion

To examine the applicability of general usability design guidelines regarding AGV-UIs, an experimental study was conducted to compare a UI designed by functional, technical requirements and a UI designed by applying usability guidelines. The results showed that a UI based on general usability guidelines revealed significant better task performance, perceived usability, and satisfaction. Also, completion time was significant lower. In addition, ease of use was rated as ‘excellent’ and all subjects preferred this user interface (Bangor et al. 2008). Still, participants expressed additional possibilities for improving efficiency and preventing errors while UI-based interaction with an AGV. All recommendations from participants seem generalizable to several applications in the industrial context. Therefore, in this study the combination of quantitative and qualitative data showed added values. Quantitative data enable estimations of possible gains and specific erroneous actions of participants while qualitative data allow to derive specific, detailed usability problems. Involving users as part of a user-centred design process should therefore occur already in early development stages (DIN e.V. 2020).

The laboratory study limits generalizability of results. Although the study tasks were designed to create a realistic and complex interaction situation with several sequential actions, participants were probably aware of missing criticality of errors and motivated to achieve good performance which could lower completion time. Still, comparative results of both UIs remain representative although absolute gains of applying design guidelines for process efficiency cannot be derived from laboratory settings. Overall, task completion rate was very high with both UIs and representativeness of applied task complexity for AGV controlling in practice should be examined in further studies.

To conclude, the application of usability guidelines in industrial context is not only beneficial for efficiency and product design purposes, but also for quality control and safety in general. Especially when interacting with automated systems, users can benefit from self-explanatory UIs to cope with unexpected and/or untrained situations.

The constant study of emphasized research questions needs to be an ongoing task for the human-machine-interaction community as automated systems or systems supported by artificial intelligence are continuously introduced and integrated into modern working environments. This becomes even more problematic as automated systems are not only developed to relieve humans from simple repetitive tasks, but will also be able to make their own autonomous decisions to solve more complex tasks in the future. This raises the research question regarding appropriate trust levels when directly interacting with such systems as constant monitoring is a demanding task for humans. Regarding the operator’s role in questioning the systems decision-making processes, monitoring is becoming increasingly complex because transparency of decisions by artificial intelligence is often not given. Still, knowing system states and explication of reasons for decisions is important for human-automation trust in high quality industrial processes. Both scenarios can benefit from cognition supporting UIs. The rather simple application of usability guidelines for industrial interface design in the field of AGVs showed the potential for problem solving even with novice users and should therefore continuously be applied in the industrial context.

5. References

Bainbridge L (1983) Ironies of automation. Automatica 19:775-779.

Bangor A, Kortum P, Miller J (2008) An Empirical Evaluation of the System Usability Scale. International Journal of Human-Computer Interaction, Volume 24:574–594.

Brooke J (1996) SUS: A “quick and dirty” usability scale. In: Jordan P, Thomas B, Weerdmeester B (Eds) Usability evaluation in industry. London: Taylor & Francis, 189–194.

DIN e.V., Deutsches Institut für Normung (2020) Ergonomics of human-system interaction - Part 210: Human-centred design for interactive systems, German version. EN ISO 9241-210:2019.

Lewis JR (1991) Psychometric Evaluation of an After-Szenario-Questionnaire for Computer Usability Studies: The ASQ. ACM SIGCHI Bulletin 23:78-81.

Luca H (2011) Usability-Studie zu KonSearch: Evaluation der neuen Literatursuchmaschine der Universität Konstanz. Accessed Nov 29, 2021. https://kops.uni-konstanz.de/bitstream/handle/123456789/16842/Luca.pdf?sequence=1.

Nielsen J, Molich R (1990) Heuristic evaluation of user interfaces. In: Chew JC, Whiteside J (Hrsg) CHI '90, empowering people: Conference proceedings, April 1-5. Seattle: Association for Computing Machinery, 249–256.

Pospeschill M, Siegel R (2018) Methoden für die klinische Forschung und diagnostische Praxis: Ein Praxisbuch für die Datenauswertung kleiner Stichproben. Berlin, Heidelberg: Springer.

R Core Team (2019) R: A language and environment for statistical computing. R Foundation for Statistical Computing. Accessed Dec 12 2019. https://www.R-project.org/.

Thielsch, MT (2017) Toolbox zur kontinuierlichen Website-Evaluation und Qualitätssicherung, Version 2.1. Köln: Bundeszentrale für gesundheitliche Aufklärung (BZgA).

Tomczak MT, Tomczak E (2014) The need to report effect size estimates revisited. An overview of some recommended measures of effect size. Trends in Sport Sciences 21:19–25.

Wessel D, Attig C, Franke T (2019) ATI-S - An Ultra-Short Scale for Assessing Affinity for Technology Interaction in User Studies. In: Proceedings of Mensch und Computer 2019 (MuC'19). New York: Association for Computing Machinery, 147–154.

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