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VISUAL REPRESENTATION OF ALARMS AND ERRORS IN OPERATOR INTERFACES

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Abstract: *This study delves into the intricate interplay between visual cues, user behavior, and stress-induced responses within operator interface design, particularly focusing on conveying alarms and errors. Through a comprehensive exploration of different visual cues, such as color and layout, the research highlights their impact on user comprehension and reaction to critical scenarios. The study demonstrates that while distinct visual indicators are effective in capturing attention, the response to varying types of errors demands nuanced design strategies. The findings also underscore the significance of tailored training and education programs, considering diverse user demographics and generations. Furthermore, this study identifies promising avenues for further research, including the impact of color choice, adaptive interfaces, and long-term user experience. By integrating cognitive and behavioral insights, operator interfaces can be optimized for enhanced user response during high-stress situations, ultimately contributing to improved system reliability and safety.*

Key words: *Operator interface, alarms, design strategies, system reliability, safety*

1. INTRODUCTION

Large-scale industrial facilities are equipped with numerous sensors and actuators, along with wired or wireless communication networks encompassing numerous clients and numerous control loops. Every element within these facilities is vulnerable to malfunctions that can disrupt the smooth functioning of the control system. Such disruptions can lead to subpar performance, instability, system failures, or even perilous situations [1]. Given the growing complexity of process control systems and the escalating expectations for quality, cost-effectiveness and safety, it is imperative to swiftly identify faults and apply suitable remedies. Fault detection has been an extensively explored domain in both academic and industrial realms over recent decades. A diverse array of fault detection techniques has been developed and is documented in the available literature [2]. To illustrate the practical applications and implications of these fault detection techniques, this paper narrows its focus specifically on their implementation in wastewater pumping stations, serving as a representative example of critical subsystems in large-scale industrial facilities. Vital part of industrial facilities can be observed in wastewater pumping stations. Wastewater pumping stations are intricate facilities responsible for transporting wastewater to wastewater treatment plants (WWTPs) or further into the gravity sewer system. If a sewage station functions as a pumping station as well, any malfunction has a more pronounced impact on its operation compared to other facilities. Moreover, operational failure of a pumping station can result in the breakdown of the entire sewer system . Therefore, this contribution will address the comparison of alarm windows on operator panels for a wastewater pumping tank [3].

The most crucial component of such a system is the pump [4]. A pump is a device that can be specified as a type of energy machine that, through static or dynamic means, enhances the potential, pressure, or kinetic energy of fluids during their transport. The pump facilitates the conversion of supplied mechanical energy, which is subsequently utilized for the transfer of matter or energy. The transfer of matter involves a pumping process characterized by conveying a specific quantity of fluid from a storage tank to a designated location. Energy transfer is a hydraulic drive or a qualitative conversion of energy into hydrostatic transmission.

The fluid, often serving as the carrier of energy, can be substances such as oil or other liquids with highly favorable lubricating properties. Fundamentally, a pump employs a vacuum at the inlet to draw fluid into the reservoir and subsequently employs pressure to discharge it [5]. We conducted our study using two versions of alarm windows one tailored for software errors and another for physical malfunctions. Each version exhibited distinct visual characteristics, with the design for software errors being seamlessly integrated into the system. For physical malfunctions, the design was developed based on established standards.

2. METHODOLOGY

In our study, we developed a control program and operator panel graphic interface (Fig. 1.) to manage such a station, incorporating two control modes: manual and automatic.

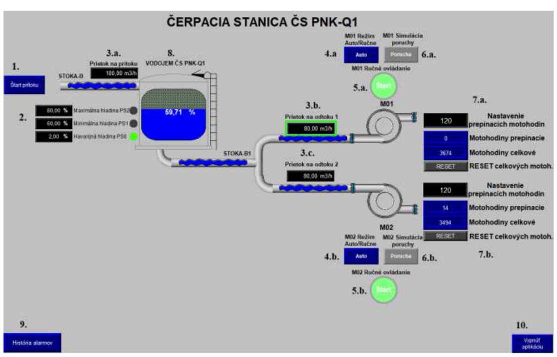

Fig. 1. Graphic interface

We created a simulation that includes two pumps, M01 and M02 (Main and Backup pump). From a safety perspective, the pumps are safeguarded by a critical minimum value to prevent pump suction cavitation.

These values can be adjusted within a range of 0 to 100. In case of erroneous manipulation, a software error type manifests, serving as a validation mechanism for our solution. Under automatic control, the pumps operation hinges on the simulated wastewater level in the collection tank of the sewage pumping station. The wastewater level is sensed by simulated float sensors. Minimum, maximum, and critical maximum values are also monitored by float sensors.

The operation and malfunction of pumps M01 and M02 are signaled on the operator panel through an alarm screen for physical errors. We encompassed several potential malfunctions, including power loss to the pumps, exceeding minimum, maximum and critical maximum wastewater levels and surpassing permissible pump operating hours.

Software errors can further be induced by disconnecting the program from the simulation software, surpassing other mathematical intervals for values like flow rate, maximum and critical maximum values. The operation and malfunction of pumps M01 and M02 are indicated by light signals on the operator panels. Additionally, a comprehensive fault, encompassing power loss, maximum critical wastewater level in the collection tank and other malfunctions, is also signaled.

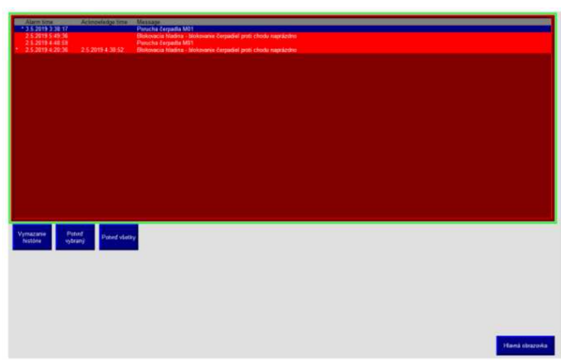

Fig. 2. Alarm History

The alarm history screen appears upon pressing the "Alarm History" (Fig. 2.) button located at the bottom-left corner of the main screen. This screen displays a list of alarms from the pumping station. The operator panel is configured to retain the most recent 50 alarms. Each entry in the list includes a descriptive text of the alarm and whether the alarm has been acknowledged or not.

The screen contains three buttons on the bottom-left bar and one button on the bottom-right bar, facilitating straightforward display operation. Clearing the history will remove all previous malfunction records. Acknowledge Selected is used to confirm information about a specific error. Acknowledge All confirms information regarding all unacknowledged errors. The Main Screen button takes us back to the Main screen.

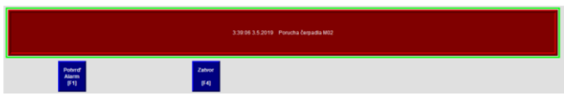

Fig. 3. Alarm screen

The alarm screen (Fig. 3.) is displayed at the moment of a malfunction. It shows a record and description of the specific alarm. It appears only at the top of the screen and doesn't cover the entire Main display.

A malfunction in a particular section of the sewage station is indicated by highlighting the corresponding element in red on the Main display. Two buttons are located on the bottom bar. The first button serves the same purpose as "Acknowledge Selected." The "Close" button is used to close the error message.

Fig. 4. Diagnostic screen

The diagnostic screen (Fig. 4) becomes active when a software error is encountered, such as when an incorrect flow value, which is outside the predetermined range is entered. This screen not only provides an immediate alert about the error but also preserves the details pertaining to it. This feature is inherently embedded within every project developed in FactoryTalk View Studio, where it encompasses all the diagnostic logs from the panel's operation.

The control program essential for driving the operation of this panel was meticulously developed utilizing RSLogix MicroLite. For simulative observations, tools such as RSLinx Classic Lite and Logix Emulate 500 were employed. Further, to simulate the operational panel that was crafted in Factory Talk View Studio ME, the Test Application feature within Factory Talk View Studio was leveraged.

This diagnostic screen serves a dual purpose; it is both a comprehensive record of activities and a substantial check on human interactions with the system, allowing for an analysis of human factors in operation. The interface of this screen presents a list of diagnostic errors, each accompanied by descriptive text outlining the error and related information, with seven functional buttons located on the bottom bar. The "Clear" button, the first among them, is designed to erase a single record from the log.

Post development and integration, the system was activated, and the simulation panel was exposed to operations by two distinct groups of individuals: professionals familiar with the operation and laypersons without prior exposure, to observe the varying interactions and responses between them.

3. RESULTS

Both groups consisted of a sample of 10 individuals each. After alternating between the two groups, the results were clear: 100% of professionals were able to comprehend both physical error alerts in the alarm window and software-related issues in the diagnostic window stemming from software errors (Table 1).

Table 1

Part of data from group of professionals

			Physical error			Software error		
	Gender	Age	Able to react	Reaction time [s]	Comprehension of alarm	Able to react	Reaction time [s]	Comprehension of alarm
1.	M	22	YES	3,2	YES	YES	4,1	YES
2.	M	26	YES	3,1	YES	YES	4,3	YES
3.	M	25	YES	3,5	YES	YES	4,8	YES
4.	M	26	YES	4,1	YES	YES	4,9	YES
5.	M	47	YES	5,0	YES	YES	14,3	YES
6.	M	52	YES	4,2	YES	YES	13,2	YES
7.	M	50	YES	5,1	YES	YES	5,1	YES
8.	M (deaf)	49	YES	4,9	YES	YES	11,1	YES
9.	F	25	YES	3,6	YES	YES	4,2	YES
10.	F	51	YES	5,4	YES	YES	10,1	YES

Table 2

Part of data from group of laypersons

			Physical error				Software error			
	Gender	Age	Able to react	Reaction time [s]	Comprehension of alarm	Grasps of steps	Able to react	Reaction time [s]	Comprehension of alarm	Grasps of steps
1.	M	22	YES	10,1	YES	YES	YES	30,2	YES	YES
2.	M	23	YES	10,6	YES	YES	YES	35,6	YES	YES
3.	M	28	YES	22,1	YES	YES	YES	41,3	YES	NO
4.	M	27	YES	18,1	YES	YES	YES	50,3	YES	NO
5.	M	50	YES	45,2	YES	YES	YES	110,8	YES	NO
6.	M	59	YES	40,5	YES	NO	NO	XX	YES	NO
7.	M	61	YES	65,3	YES	NO	NO	XX	YES	NO
8.	M	62	YES	70,2	YES	NO	NO	XX	YES	NO
9.	F	25	YES	15,6	YES	YES	YES	59,3	YES	NO
10.	F	52	YES	44,4	YES	YES	YES	80,3	YES	NO

In the case of the laypersons group, when presented with a physical alarm, everyone understood it as an error notification; however, only 70% were able to grasp the subsequent steps required to eliminate the error notification. When confronted with a software-related diagnostic error, only 20% of the examined sample comprehended the situation. This subgroup primarily comprised younger individuals who, in the situation, remained composed and read the diagnostic message rather than panicking (Table 2).

The impact of visual cues on user response and behavior is clearly discernible from the study's results. In instances of physical errors, the introduction of a large, conspicuously colored window was remarkably effective in capturing the attention of nearly every participant, successfully alerting them to the presence of an error. However, the occurrence of a problem triggered a stress response among users. This heightened emotional state, inherent in such situations, often hindered the ability to think and respond rationally, regardless of the clear visual cue.

Consequently, not everyone was able to effectively address the situation immediately. Switching focus to software-related errors, a different trend emerged. Participants, while not under the same level of stress, encountered difficulties in interpreting the problem. Colors like blue and gray, commonly associated with neutral or standard interface elements, failed to convey the urgency of the error.

The use of color as a singular indicator for different types of issues proved to be insufficient in conveying the essence of the problem. This raises the necessity for employing distinctive visual markers, beyond just colors, to provide clear differentiation between various types of errors. These markers should be carefully designed to offer an intuitive and immediate understanding of the nature and severity of the problem, even without the need for detailed reading. Furthermore, the study highlighted an intriguing generational contrast.

The older generation exhibited a greater need for comprehensive explanations regarding the safety protocols associated with operating the operator panel. This implies that training and onboarding programs for laypersons, especially those from older age groups, would benefit from allocating more time for education and clarification of safety practices [6].

This additional training time would better equip them to navigate and respond effectively to unexpected scenarios. In conclusion, the study underscores the importance of not only visual cues but also the need to consider user reactions under varying circumstances. Effective design should take into account the psychological and cognitive aspects of user interaction, especially in high-stress scenarios and adapt to the diverse user demographics to ensure safe and efficient operation of systems like the operator panel [7].

4. FURTHER RESEARCH

While this study has illuminated several critical aspects of operator interface design, there remain several avenues for further research that can contribute to refining and advancing this field. These research directions encompass a range of topics, each with the potential to enhance the usability, safety, and overall effectiveness of operator interfaces:

- Impact of Color Choice: Investigate how different color schemes and combinations impact user perception and response to alarms and error messages. This could include testing a wider range of colors and their effectiveness in conveying urgency, severity, and problem type.
- User Interface Design: Explore alternative user interface designs for displaying alarms and errors. This could involve experimenting with different layouts, iconography, and information hierarchy to optimize user comprehension and response.
- User Training and Education: Conduct in-depth studies on the effectiveness of training programs for different user demographics, including the older generation. Assess the impact of various training methods on their ability to understand and respond to different types of alarms and errors.
- Human Factors Analysis: Perform a comprehensive human factors analysis to identify the specific cognitive and emotional challenges users face during stress-induced scenarios. This could lead to the development of targeted design solutions that mitigate these challenges.

- Comparative Study with Real-World Scenarios: Extend the research to real-world scenarios involving actual industrial facilities. Assess how the findings translate to operational contexts and if there are additional factors in play when users are faced with real-time consequences.
- Multimodal Feedback: Explore the integration of audio or haptic feedback in addition to visual cues. This could enhance the effectiveness of alarms and error notifications, especially in environments where visual attention is divided or compromised.
- Long-Term User Experience: Investigate the long-term impact of stress-related responses on user experience, performance, and well-being. This could involve longitudinal studies to assess the potential for stress-induced burnout or cognitive fatigue.
- Comparative Studies Across Industries: Extend the research to different industries, such as aviation, healthcare, or transportation, to evaluate the transferability of findings and design principles to various high-stress environments.

By delving into these areas, we can continue to refine our understanding of human interaction with complex systems, leading to improved user interface designs, enhanced safety protocols, and optimized user responses during critical scenarios [8].

5. CONCLUSION

In conclusion, this paper has provided valuable insights into the intricate relationship between visual cues, user behavior, and stress-induced responses in the context of operator interfaces.

The effectiveness of conveying alarms and errors in critical systems requires a delicate balance between design clarity and user comprehension, especially during high-stress scenarios.

The study illuminated the impact of distinct visual cues, such as color and layout, on user response to alarms and errors.

While a prominently colored window proved effective in capturing attention during physical errors, the response to software-related issues highlighted the limitations of relying solely on color to convey urgency.

This underscores the importance of employing multiple indicators and design elements for a more comprehensive understanding of different types of problems.

However, it is important to acknowledge the limitations of this study. This research did not explore the impact and effectiveness of auditory alarms, focusing solely on visual cues and user interaction.

Additionally, one participant in the study was deaf, thus potentially impacting the generalizability of the findings to the broader population and highlighting a need for inclusive design considerations in future studies to account for a diverse range of user needs and abilities.

Furthermore, the varying reactions between professionals and laypersons, as well as across different generations, underline the need for tailored training and education programs. Addressing the specific needs of different user demographics can enhance their ability to understand, interpret, and respond effectively to alarm and error situations.

As we navigate the complex landscape of operator interface design, the identified research avenues present exciting opportunities for further exploration.

By delving into these areas, we can advance our knowledge of human interaction with critical systems, refine design principles, and ultimately contribute to safer and more efficient operations.

In the end, the integration of cognitive and behavioral insights into operator interface design can drive the development of interfaces that empower users to navigate stress-induced scenarios with confidence, ensuring the continued reliability and safety of critical systems.

6. ACKNOWLEDGEMENT

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REREPREZENTAREA VIZUALĂ A ALARMELOR ȘI ERORILOR ÎN INTERFEȚELE PENTRU OPERATORI

Rezumat: Această studie explorează interacțiunea complexă dintre semnalele vizuale, comportamentul utilizatorilor și răspunsurile induse de stres în cadrul designului interfețelor pentru operatori, cu accent pe transmiterea alarmelor și erorilor. Prin explorarea cuprinzătoare a diferitelor semnale vizuale, cum ar fi culoarea și dispunerea, cercetarea evidențiază impactul lor asupra înțelegerii și reacțiilor utilizatorilor în situații critice. Studiul demonstrează că semnalele vizuale distincte sunt eficiente în captarea atenției, dar răspunsul la diferite tipuri de erori cere strategii de design subtile. Descoperirile subliniază, de asemenea, importanța programelor de instruire personalizate, având în vedere demografia diversă a utilizatorilor și a generațiilor. În plus, această cercetare identifică direcții promițătoare pentru cercetări ulterioare, inclusiv impactul alegerii culorilor, interfețe adaptive și experiența utilizatorului pe termen lung. Prin integrarea perspectivelor cognitive și comportamentale, interfețele pentru operatori pot fi optimizate pentru a stimula răspunsul îmbunătățit al utilizatorilor în situații de stres ridicat, contribuind în cele din urmă la îmbunătățirea fiabilității și siguranței sistemelor.

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