A Novel Design for an Ultra-Large Screen Display for Industrial Process Control

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Abstract. While large screen display technology has been used in process control rooms for many years, it still remains an immature area where there are few examples of successful utilization of its potential benefits in providing essential support to control room crews. We present a solution claimed to represent a major breakthrough in the transfer of modern Human System Interface concepts for process control from the research community to large-scale industrial application. The design principles and approaches that have emerged from this interaction between research and real-life problems are presented, including the novel design challenges imposed by the use of a new type of ultra-large screen technology.

Keywords: Human-computer interface display design, large screen, industrial applications, human-centered design, visual constraints, information design, ecological interface design.

1 Introduction

This paper presents the foundations, rationale and novel features of a new design of an ultra-large screen display for the control room of a new process plant built by Statoil in Norway. This work is claimed to represent a major breakthrough in the transfer of modern Human System Interface (HSI) concepts for process control from the research community to large-scale industrial application, and opens important opportunities for further study of the impact on operator satisfaction and behavior as well as performance effects from introducing such solutions to real-life operational settings.

The authors' perspective has been formed by our experiences in working at the intersection between practically oriented design approaches used in industry and the more formally defined approaches derived from cognitive systems engineering and similar theory. Our purpose is to bring to the attention of HSI research community a large joint effort by Norwegian industry and researchers focusing on the utilization of large screen display technology to improve safety, efficiency and work environment in control rooms. The design project described in this paper is typical for an industry project in that it tackles "ill-defined" problems under constraints very different from

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those found in most academically oriented HSI design work that is published. The main contributions of this paper is thus to report challenges, issues, principles and lessons learned that have emerged from this project that we believe to have general relevance and interest for HSI research community and industry users.

It is beyond the scope of this paper to describe all relevant HSI issues that are involved in such a project. Highlighted here are the challenges of the design phase, which included the creation of a novel, relevant, efficient, and usable dynamic visualizations of the plant state. Conducting a user-centered design process on a highly innovative concept is also described. And finally we discuss how the display design faced novel challenges due to the combination of a new type of large screen technology and spatial layout. The "ultra-large screen" (ULS) concept leads to a breakdown of the previously sharp boundaries between room layout design and layout of information within displays.

2 Motivation for the Development of the New Design

The Snøhvit plant is a novel plant design for producing LNG (Liquefied Natural Gas). It is designed for a low staffing level, and Statoil has put much effort into the development and application of advanced technologies to meet the high efficiency, safety and environmental standards. One of the challenges such a new plant presents to HSI designers is that there is no plant operation or user experience available. The basic HSI system consists of four operator workstations for individual use with four screens each, with approximately 1000 detailed displays and 20 system-oriented overview displays.

Numerous challenges face control room operators responsible for monitoring and controlling this highly complex plant. For providing an information source for plant-wide overview, the control room design featured an exceptionally large 16 m x 1.5 m large screen display that created a continuous display surface on a curved wall enclosing the crew.

While large screen display (LSD) technology has been used in process control rooms for many years, it still remains an immature area where there are few examples of successful utilization of its potential benefits in providing essential support to control room crews. Based on traditional piping and instrumentation diagrams, alarm lists, etc.; the principles of process control HSIs in industry have remained basically unchanged for decades, despite their well-documented limitations in supporting abnormal situation management and other operational challenges. And while large screens may be considered a new type of presentation medium in the control room, they are typically used merely to show displays based on the traditional principles.

Both Statoil and the HSI design research community at the Institute of Energy Technology (IFE) in Norway recognized that Snøhvit represented a unique window of opportunity to advance the state-of-the-art in display design in industry towards solutions that improve situation awareness and crew collaboration while reducing workload and human error.

3 Design Rationale, Approach, Features and Review

The overall challenge presented to the Snøhvit design team by Statoil was to use advanced concepts from research to turn the "ultra-large screen" into a highly useful and usable tool to supplement and overcome the shortcomings found in other parts of the total HSI. The solution should significant improve operators ability to monitor and handle the safety, production and environmental issues in this complex plant. While the use of novel concepts from the research frontier were highly welcome, it was also necessary to consider the issue of user acceptance in a real-life operating environment. This is discussed in section 3.1.

The so-called "Information-Rich Design" (IRD) concept [4], [1] is an alternative HSI concept developed to supplement and potentially replace traditional displays used for process control and monitoring. The concept has emerged from IFE's interaction with a broad range of industry problems and users over a decade, and the Snøhvit solution represents the most extensive application of this concept.

Section 3.2 describes the principles and features of the IRD and its application and development for the Snøhvit solution in terms of selection and structuring of information content and visual form of information presented. Layout design and physical ergonomic issues are discussed in the next chapter.

Section 3.3 presents a brief review of a key visual element, the *ControlStar*.

3.1 Design Approach and User Involvement Process

Active involvement of users and other domain experts was essential to establish the clear understanding of work domain constraints and operator tasks required to tailor the display design to the target plant and user group. A user-centered (not user-driven) involvement process in accordance with ISO 13407 [8] was conducted, and a permanent multi-disciplinary working group including operators, process and automation personnel and vendor representatives was formed for this purpose. In a series of iterations of different design solutions the design team used its multi-disciplinary background comprising interface design, human factors and process domain expertise to cooperate closely with this working group in creating an appropriate and acceptable solution.

The design team had broad experience with development and evaluation of different HSI solutions for process control applications in the nuclear and petroleum domains. This work has also included the use of different theory-based frameworks that assume that systematic methods based on formal analyses are essential for handling a complex design task. However, a more appropriate model for characterizing the approach used by the IFE design team in projects such as Snøhvit is the "Reflecting Practitioner" model proposed by Schön [9]. This model aims to capture the principles underlying the actual work approaches used by a diverse range of professions dealing with ill-defined problems (such as design) in real-world settings. The model is fundamentally different from the idealized approaches and methods often taught academically in many professions, including interface design, and we find it a fitting description of how experienced practitioners in interface design engage in a rapid cycle of prototyping, "micro-experiments", reflection, problem reframing and idea generation. IFE's design group has applied this approach across different research and industry projects to pursue the two-fold goals of supplying innovative, yet practical large screen design solutions to plants, and to identify and formulate the concepts and principles described in the next section.

The design team had substantial experience using the Ecological Interface Design framework [16], [2], and the Snøhvit design borrows several goals and principles from EID. This includes the recognition that interface design is able to form users' mental models of their work domain and shapes their mental strategies, a clear conceptual separation of information content and visual form, and the principle that information requirements are derived from understanding work domain characteristics and constraints rather than task analysis or iteration on existing designs. Information is also provided at various levels of abstraction, and novel visual forms are used to utilize human perceptual capabilities through extensive use of analog and configural display formats that aim to facilitate direct perceptual processing. However, several of the guiding principles in the Snøhvit design cannot be attributed to EID, which does not address many of the primary issues involved in designing large screen overview displays; the selection of an optimal sub-set of the total information for presentation, choosing efficient visual forms for overview purposes, and ensuring user acceptance. While the Abstraction Hierarchy concept was used to find relevant abstractions levels and constraints to include in the design, the sort of complete and formal Work Domain Analysis that forms the basis of a "formal" EID was deliberately not performed. Therefore, while the visual design aims to create an environment for facilitating ecological interaction [5], the Snøhvit solution does not have the characteristics required to adapt the claim made by the EID theory that knowledge-based problem solving behavior in unanticipated situations is explicitly supported.

3.2 The "Information-Rich Design" Concept for Large Screen Displays

The set of principles that constitute IRD have been created to facilitate certain changes in operators' strategies for monitoring and control that are believed to be beneficial. The design should exploit instinctive behavior by making key information available in fixed locations. It should serve as the preferred source for overview information in important operational situations by supporting early detection and initial diagnosing. Both alarm-based and pre-alarm detection strategies should be supported to be flexible and support users in adapting more proactive monitoring strategies. It is aimed to provide a high data density in the display without causing information overloading. The usability of the display must be explicitly considered for different operational situations.

Information Content – Rationale, Selection and Prioritization. The starting point for an Information-Rich Design solution is an effective set of principles for guiding the selection, structuring and prioritization of the information content to be presented. The target users must be defined clearly, as well as the range of operational modes that the display should be explicitly designed to support (this typically includes normal and disturbed operation as well as process shutdowns and emergency handling).

In the selection of key information for inclusion in a large screen overview several dimensions must be considered. The first is to ensure acceptable situation awareness in terms of providing efficient monitoring of relevant safety and production data which are guided by the nature and severity of *consequences* of failing to detect or interpret plant deviations. Including key performance indicators (KPIs) based on product quality and quantity, efficiency, and environmental parameters is important for maintaining the overall view of the plant performance, and integrating the *key alarm concept* as defined by the EEMUA Alarm Guide [10] is another way to support the alarm handling and total system usability in upset conditions. Information should also be selected based on its ability to support monitoring anticipated process bottlenecks and pay special attention to supporting collaboration and coordination of tasks within the crew.

The other type of criteria for information selection aims to reduce the physical and cognitive workloads of operators by providing direct visual access to *frequently used* data.

Plant and process expertise including work domain knowledge and task requirements must be obtained by the design group. The Snøhvit project was presented with particular challenges in this phase since at the time of design there were no operating experiences, procedures or experienced users available. Instead the requirements had to be extracted from basic plant documentation and dialogues with domain-experts and users from other types of existing plants.

Visual Form of the Information Presented. The visual forms used in IRD are designed to be perceived and interpreted by users with minimum effort by utilizing their powerful human perceptual capabilities. The main influence on the graphical features of the IRD approach has been the principles of Information Design by Tufte [11], [12], [13] which advocate the use of mature graphical design principles for de-cluttering to achieve information-dense displays. Unlike the digital coding of data widely used in current process control displays, IRD uses analog coding extensively to allow processing with little effort and large parallel capacity. Visual elements are designed so that multiple reading strategies are supported; a brief glance should be enough for quick detection of problems or reassurance that no major problems exist, while closer inspection of details within the display should also be possible in other situations. This is supported by the use of multiple visual layers created by careful use of colors and other graphical means to achieve layering and separation effects. The salience of each layer reflects the importance, so the display may be quickly scanned for abnormal states by scanning only the most easily visible features of the total display.

Basic usability principles regarding font sizes and legibility must be respected in all display design work. An additional guiding principle in IRD is that making the design aesthetically attractive also contributes to its efficiency, inspired by the “emotional design” concept by Norman [7].

A typical feature in IRD is the use of mini-trends that are aligned and normalized to facilitate rapid visual scanning for anomalies, as shown in Fig. 1. More complex configural formats have also been developed for visualizing multivariate data in a way that utilizes emergent features. One example of such a display is shown in Fig. 2.

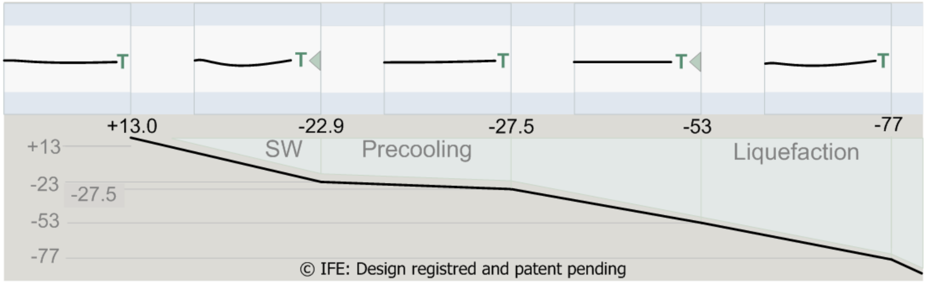

Fig. 1. This temperature profile with five minitrend elements creates a visual scanning band that makes it easier for the operator to monitor 5 key variables in the plant. When the temperature is normal and stable the different trends will be aligned. Note that the alarm areas of each minitrend together form a band. Below, the temperature profile shows the same parameters in relation to each other in a common scale to give the operators information about the relative performance of each subsystem.

The two fundamental IRD principles for optimizing the total layout of visual elements are: 1) Provide a very simple visual structure to allow easy scanning, orientation and reading of data-dense displays, and 2) the layout should also provide a sufficiently correct picture of the plant system topology. Finding a solution that satisfies these different and often competing constraints is one of the major efforts involved in designing an IRD display. For the Snøhvit project the special ergonomic requirements from the ULS solution added significantly to this design challenge; this is elaborated in chapter four.

3.3 Design Guideline Review

We argue that the element shown in Fig. 2 complies with the review guideline NUREG 0700 section 1.2.10 [14] regarding configural formats. The ControlStar element provides a rapid transition between high-level functional information and low-level information as detailed parameter values through emergent features. The high-level functional view informs the user at a glance about the overall situation of the whole sub-system. A closer view gives information about the specific variables. The normalizing and the regular shape functions as a reference aid for the operators in recognizing abnormalities for the whole sub-system. The polygon representing actual set of measurements should be in the middle covering the dashed (ideal) line in a normal situation. Thus, the deviation will emerge when a deviation increase. The use of color and line thickness in the two polar diagrams makes these two dynamic polygons appropriately salient for the basic visual inspection task. Additionally, the deformation of the polar diagrams in case of deviation is another visually salient property. Finally, the display element gives an intuitive presentation of the situation (aggregates a substantial amount of data from a meaningful unit of plant operation for quick inspection of controller performance and bottlenecks) without being too complex.

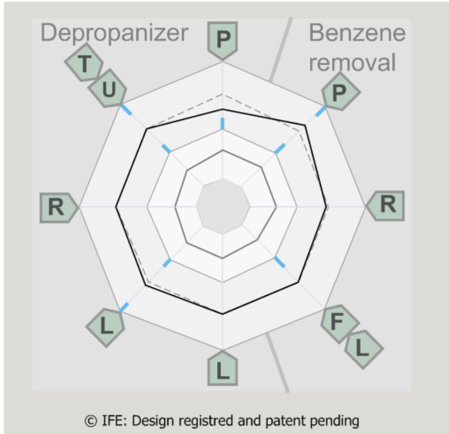

Fig. 2. The ControlStar is based on the well-known Polar Star displays [3]. The outer layer shows the mode of the control structures (single or cascade controllers in auto, manual or cascade). The middle layer is a normalized polar star showing the controlled measurements (of the outer/master controller in case of a cascade) relative to set point and high/low range limits. This layer also shows the H/L alarm configuration as lines along the spokes. The inner layer is a non-normalized polar diagram of the controller output of the controller (the inner loop in the case of a cascade structure).

4 Total Display Layout and Ergonomical Challenges

A fundamental principle is that the large screen display solution together with the rest of the HSI must interact as a whole with the entire crew. When developing the total solution the design team had to form a visual display design for the extremely large surface and huge amounts of information. The Snøhvit ultra-large screen display solution posed special design challenges to help users orientate and correctly recognize information sources within the total display. A single operator cannot manage to get a complete overview or attend to the whole process, but the layout of the total display is carefully chosen, and allows each operator to attend to all sub-systems for which he/she has control and supervision responsibility. One major goal was to minimize the operators' viewing difficulties when monitoring and controlling his or her process part. The design team had to find the balance between giving complete or much information and making all the information visible while minimizing head and eye movement for the responsible operator. Therefore the design has included careful consideration about where to locate the visualization of the different systems. This process was done in close co-operation with the end-users – the operators and the process domain experts.

For evaluation of the total interaction environment it was necessary to develop a 3D VR-model of the control room including the ultra-large screen solution. During the design process different visualization proposals were evaluated in the 3D-model supporting the iterative design process.

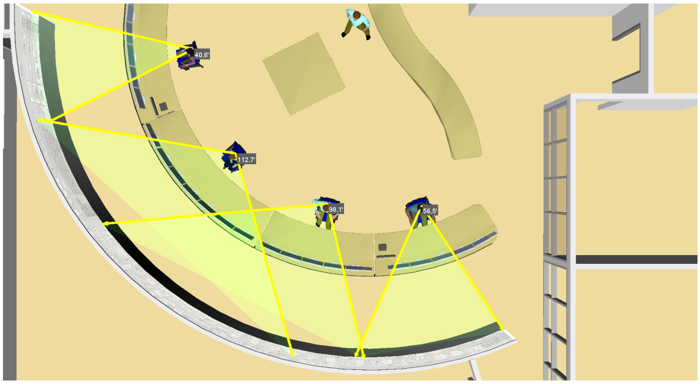

Fig. 3. A birds-eye view of the control room shows the four operators, each marked with the distribution angle for the systems responsible to monitor and control: From upper-left: The loading/storing operator (40^o), the utility operator (115^o), the main process operator (100^o), and the subsea operator (56^o). The distance from each of these four operators to the screen is about 3.5 meters. A standing operator is placed in a distance of about 8 meters to the front of the screen. The review guideline [14], stating that the operator should not be closer than half the width of the screen in order to be capable to view all, is satisfactory fulfilled for viewing the primary information areas.

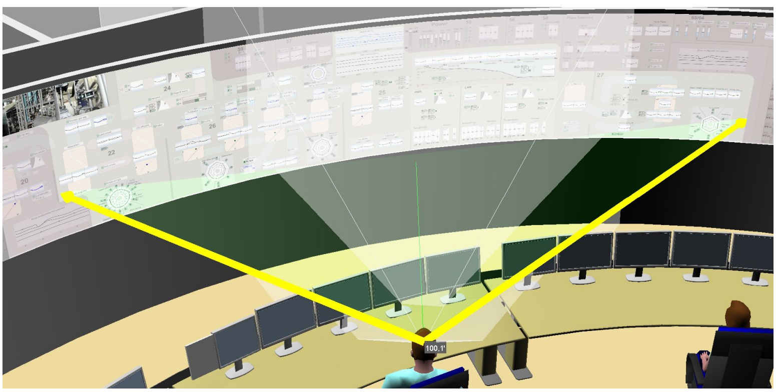

Fig. 4. This snapshot illustrates the layout for the main process operator. The semitransparent view-cone illustrates the limited screen area that the operator can fully attend at one moment during a specific task. Information to be monitored and controlled by the main process operator is distributed across a much wider display area shown between the two thick angle measures, corresponding to a total viewing-angle of 100 degrees. In this illustration the dimmed areas to the left and right indicate information defined to be of secondary or no interest to this operator. The final design include 130 IRD mini-trends, 61 controllers shown in six ControlStars (showing six to 16 controllers in each), non-trended analog coding of 80 measurements, 30 temperature measurements shown as detailed profiles for key units, about 50 temperatures in ten long temperature profiles, and about 150 temperatures in ten short temperature profiles, and four user customizable long-term trends, each of four variables.

5 Remaining Issues and Planned Further Work

Training has not been an issue in the design project, but a complex product such as the Snøhvit solution clearly requires a comprehensive training program. The learning curve for operators and the process by which they adopt the use of this kind of display are highly relevant research issues related to training. Key issues in further studies will be to observe how individual cognitive and teamwork strategies are made possible and are shaped by different features in the new large screen displays, and further analyze how these strategies may affect operator and plant performance [6]. Results from EID research indicate that users' holistic vs. serialist cognitive styles may be a factor that influence how successfully users adopt the use of visually complex displays in their work strategies [15]. This is potentially relevant also for the type of display designs presented here.

A large, joint-industry funded research project is currently being established to evaluate and document experiences with this and other designs based on similar new ideas that are currently being introduced in a number of control rooms in Norwegian oil and gas industry. Data will be collected from different control rooms in the form of field observations, interviews, questionnaires, and plant and alarm system performance data. In addition to addressing the research issues outline here, this project also aims to establish better design guidelines based on what emerges as best practices.

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References

1. Braseth, A.O., Veland, Ø., Welch, R.: Information Rich Display Design. In: Proceedings of the Fourth American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation, Controls and Human-Machine Interface Technologies, Columbus, Ohio (September 2004)
2. Burns, C.M, Hajdukiewicz, J.R.: Ecological Interface Design. CRC Press, Boca Raton, FL, U.S.A (2004)
3. Coekin, J.A.: A versatile presentation of parameters for rapid recognition of total state. In: Proceedings of the IEE international symposium on man-machine systems (no pagination). Cambridge, England: IEE (1969)
4. Haukenes, H., Veland, Ø., Seim, L.Å., Førdestrømmen, N.T.: Petro-Hammlab Overview Displays: Design Rationale – Experiences. In: Proceedings of the Enlarged Halden Program Group Meeting, Lillehammer, Norway (2001)
5. Gibson, J.J.: The Ecological Approach to Visual Perception, Hillsdale, NJ: Lawrence Erlbaum Associates (1979/1986)

6. Norras, L., Nuutinen, M.: Performance-based usability evaluation of a safety information and alarm system, International Journal of Human-Computer Studies, (March 2005)
7. Norman, D.A.: Emotional Design: Why We Love (Or Hate) Everyday Things. Basic Books, New York, NY, USA (2003)
8. International Organization for Standardization, Human-centred design processes for interactive systems, ISO 13407, Geneva, Switzerland (1999)
9. Schön, D.A.: The reflective practitioner: How professionals think in action. Basic Books, New York, NY, U.S.A (1983)
10. The Engineering Equipment and Materials Users Association, Alarm Systems – A Guide to Design, Management and Procurement, EEMUA 191, London, U.K (1999)
11. Tufte, E.R.: Envisioning Information. Graphics Press, Cheshire, CT, U.S.A (1990)
12. Tufte, E.R.: Visual Explanations. Graphics Press, Cheshire, CT, U.S.A (1997)
13. Tufte, E.R.: The Visual Display of Quantitative Information, 2nd edn. Graphics Press, Cheshire, CT, U.S.A (2001)
14. U.S. Nuclear Regulatory Commission, Human-System Interface Design Review Guidelines, NUREG-0700 Rev. 2, Washington D.C., U.S.A (2002)
15. Vicente, K.J.: Ecological interface design: Progress and challenges. Human Factors 44, 62–78 (2002)
16. Vicente, K.J., Rasmussen, J.: Ecological interface design: Theoretical foundations. IEEE Transactions on Systems, Man and Cybernetics 22, 1–18 (1992)