Tool-supported Comparative Visualizations to Reveal the Difference Between 'What Has Been Designed' and 'How It is Perceived' for Monitoring Interface Design

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***Abstract*—Monitoring is one of the most important tasks for an operator of a complex safety-critical system like a ship bridge or air traffic control. It is a prerequisite for good situation awareness. Designing an interface for such environments requires optimizing what is presented to the most limited resource: the operator's visual attention. But the real operator's attention distribution is hard to anticipate for a designer. Cognitive models can predict attention without the need of a functional prototype or user studies with eye tracking equipment. We propose a tool-driven process to compare graphical attention predictions from two perspectives: The operators' and the designer's one. We performed an explorative study in that we presented a designer the different visualizations. The result indicated that such a visually supported comparative analysis supports a designer in identifying differences between what has been designed and how it is perceived by the operator. Comparative visualizations also seem to stimulate the designer to reason about the design.**

Keywords—interface design; rapid prototyping; attention allocation; virtual test user

Submission type: Oral presentation paper

I. Introduction

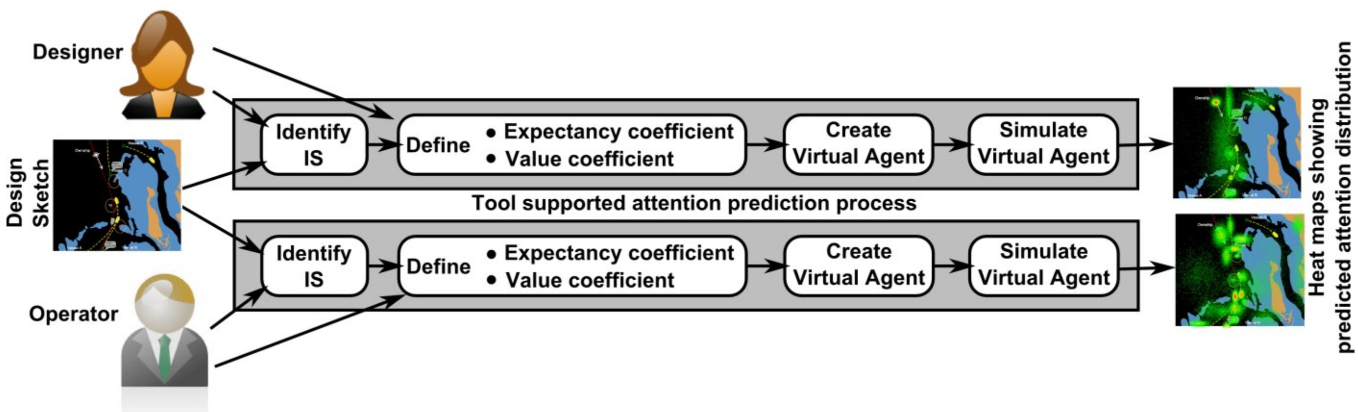
Operators of safety-critical systems spend a substantial amount of their time in monitoring the human machine interface (HMI). It is a necessary activity to decide whether the system is under control [1]. Therefore, user-centered design processes that put the operators in focus and involve them throughout the design and development carefully analyze the operators monitoring behavior to optimize their overall monitoring effort.

For system design in highly specialized safety-critical environments, such as a ship bridge or air traffic control, the access to these experts and environments for performing realistic studies is often limited: The operators are physically distributed around the world and high costs are involved to cover travel costs to a lab and to substitute their work absence. Their high degree of specialization further limits the total amount of theoretical available operators. Additionally, performing tests in a realistic environment requires an - at least partially - functional HMI prototype.

Therefore, we propose a tool-supported process that enables highly specialized operators to participate in a user-centered design process remotely in a fast and structured way. Instead of measuring attention distribution directly via eye tracking equipment, our approach relies on a simplified cognitive modeling process that predicts attention distribution on an HMI prototype.

Many aspects influence operator's visual attention distribution [2]: the saliency of information, the distribution of the information sources over the HMI, the operators' tasks, how often the operator expects relevant updates of certain information, the information value. This diversity of factors that impact the operators' attention allocation makes it difficult to anticipate it during the design process. Therefore, the operators' monitoring behavior is often analyzed by eye-tracking studies, with all the mentioned requirements listed above.

Model-based attention prediction approaches as alternatives to eye-tracking studies already exits. Wolfe [3] is a good example of a stimulus-driven and saliency-based model for visual search tasks. In contrast, the SEEV model [4] is a model for monitoring behavior, which has been applied and validated in different real-world applications [5-7]. They use algorithms to calculate the attention distribution based on several inputs from an operator. This includes the frequency with which the operator expects new information (expectancy coefficient) and a definition of how valuable the information is (value coefficient) for each information source of a monitoring display.



Tool-supported process to predict operator's attention allocation. In [12] this process was executed by the HMI designer and the operator.

A virtual operator simulation based on a computational cognitive model can also consider probabilistic aspects of behavior such as distributions of reaction times to external events or simulation of gaze sequences [8]. For monitoring tasks the SEEV model was integrated and used in different computational frameworks, like the A-SA model [9] and the cognitive architectures CASCaS [10] and MIDAS [11]. In [12] a tool-supported process has been proposed to predict operator attention. It does not require functional HMI prototypes, but works with simple design sketches.

Using this tool-supported process [12] showed that predictive models created by an HMI designer and an experienced operator differed in many aspects and reflect their respective perspective. In this paper we propose a tool-driven process to graphically compare attention predictions from these two perspectives: The remotely generated operators' one and the designer's one and explore if and which are reasonable to communicate the operator's perspective to the HMI designer.

In the following section we briefly describe the process of creating and using predictive cognitive models from [12]. In Section 3 we describe the procedure of this study and the different approaches for communicating the operator's perspective to the HMI-designer. In Section 4 we describe our observations and the findings we made, while presenting the different communication approaches to an HMI designer. Finally in Section 5, we conclude by outlining future work that needs to be done to test our findings in controlled environments.

II. Tool-based Attention Prediction Process

Fig. 1 depicts the activities that one has to perform to generate an attention distribution prediction [12]: Based on design sketches or images all information sources of an HMI are identified and graphically marked with their corresponding size and position. An information source (IS) is a physical space or area in an environment that communicates a single information to the user. The user gives a name to each IS to describe the information that is provided. Afterwards, the expectancy and value coefficients of the SEEV model (see Section I) are defined for each IS. This is done by using the lowest ordinal algorithm [4]. The tool provides support by guiding the user step-by-step through this algorithm.

After the SEEV model coefficients have been defined for all ISs, a cognitive model is automatically generated based on the cognitive architecture CASCaS, which uses the SEEV model for simulation of attention distribution [13]. The model describes a virtual operator who continuously monitors all ISs in a psychological and physiological plausible way. Simulation of the model results in a sequence of eye movements and fixations. Instead of showing the time trace of these fixations, the simulated monitoring behavior is aggregated and visualized with charts and heat maps similar to visualizations used in eye tracking studies.

We experimented with several visualizations to present the resulting predicted attention allocation. [12] gave indications that presenting a heat map stimulates the reasoning about a design, while at the same time subjects tend to over-interpret what is depicted. These observations lead us to the idea to test, if we can support a HMI designer by offering a visualization that compares the attention predictions gained by an operator with the attention distribution assumed by the HMI designer. With such visualizations, that also include the data that has been used to generate the predictions (i.e. the created visual attention model) we intend to support a designer in the systematic discovery of the operator's perspective and in learning about the impacts of design decisions for the predicted operators attention.

III. Explorative Study

In the maritime domain Electronic Chart Display and Information Systems (ECDIS) are one of the main sources of information that are monitored to support vessel navigation. In a first study [12] four subject matter experts (SMEs) of different areas (HMI designer, operator, expert for cognitive modelling, expert for situation awareness) have applied the tool supported attention prediction and analysis process to compare three different ECDIS designs. The results indicated that each role had a different perspective on the design, presumably by their different background knowledge. Thus, we perform this subsequent study to explore if generated comparative visualizations are applicable to reveal differences between the SMEs. Specifically we test whether the perspective of one SME (operator) can be communicated to another SME (HMI designer). If so, it could serve as a fast and well-structured approach for gaining feedback from remote expert users in early design phases.

The objective of this study is to present several different visualizations to the HMI designer of the previous study to gain indications, which of the visualizations has the greatest potential for revealing differences between SME perspectives. Our approach was to:

1. Identify the information that was very important for the operator SME
2. Present the different visualizations to the HMI designer SME and instruct him to think aloud while exploring the visualizations.
3. Analyze the recordings of the HMI designer, to identify
   (a) whether the designer can identify what is most important for the operator
   (b) which visualization is most helpful for the HMI designer for reflecting on the operator's perspective of the HMI, and
   (c) whether the designer can get insights that help to improve the interface design.

A. Important Information for the Operator SME

The subjects' process to predict the attention allocation was recorded and the subjects were asked to think aloud during the process. We analyzed the 4.5 hours long recording of the operator SME, a shipmaster who participated in the first study. Specifically, we were interested in capturing all information from the three ECDIS designs that the shipmaster communicated to have a high value for performing the overall navigation tasks and ended up with a list of seven information elements:

1. Course and speed vector of the own ship.
2. Time to closest point of approach to another vessel.
3. Navigation gates of planned routes for other vessels.
4. Course and speed vector of other vessels.
5. Position predictions of vessels.
6. Geographic location and cross traffic to port.
7. Lighthouses.

B. Visualizations presented to the HMI designer

The SMEs had to label each IS with a suitable name that describes the information provided by the IS. However, visualizations that show IS properties and statistics by referring to the name of the IS seem inappropriate, e.g., tabular representations, graphs or pie charts. Different SMEs marked the same information in different ways and especially used very different names for the same information source. Thus the combination of the IS name and physical area defined by the SME is of interest. Therefore, all visualizations we created are overlays of the HMI design sketches. We decided for graphical visualizations that are partially interactive. We elaborated six different comparative visualizations (see Fig. 2-5) that all are automatically generated based on the inputs of the operator and designer: the marked ISs and their corresponding ratings of the two SEEV coefficients for *expectancy* (the expected update frequency for new information) and *value*(see Section I).

1. Comparison of designer's and operator's attention allocation heat map. For each design, the heat map of the designer (Fig. 2b) and the heat map of the operator (Fig. 2c) are presented at the same time. This enables the HMI designer to easily identify and compare hotspots of attention predicted by the operator's model with hotspots predicted by his/her own model. To enable reasoning about the differences in the heat maps, an additional overlay was presented to the HMI designer that shows the boundaries and names of all IS defined by the operator (Fig. 2a). The HMI designer can use this to relate hotspots in the heat map to ISs defined by the operator.

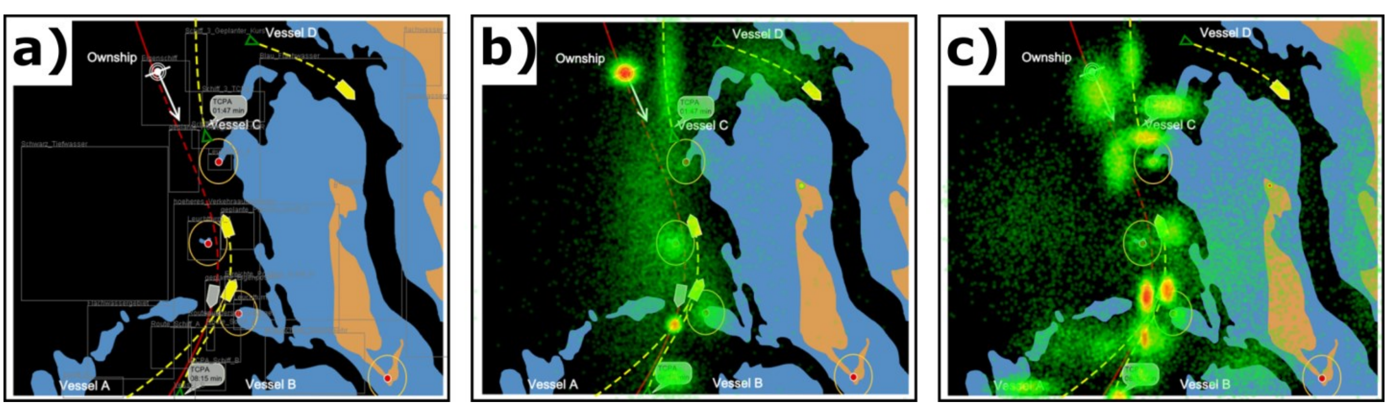


Fig. 2. Heat map visualization. a) The boundaries of the operator's ISs used as reference for the interpretation of the operator's heatmap. b) The heat map resulting from the simulation of the cognitive model defined by the operator. C) The heat map resulting from the simulation of the cognitive model defined by the operator.

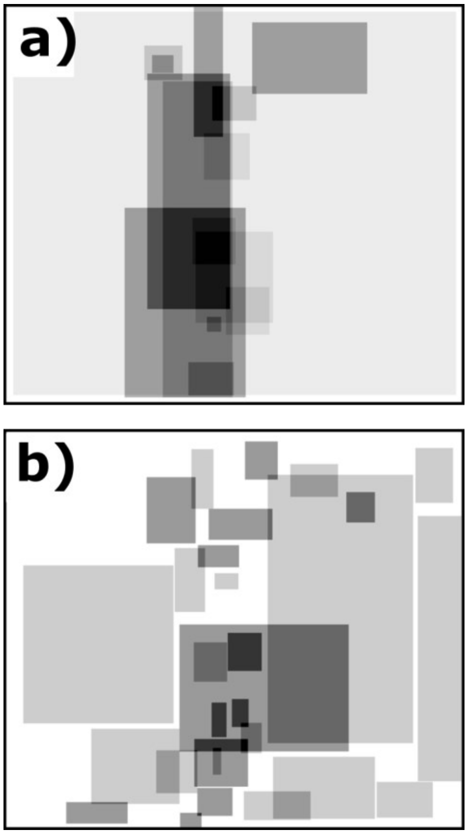


Fig. 3. Colorization of IS based on expectancy coefficients defined by (a) the HMI designer and (b) the operator.

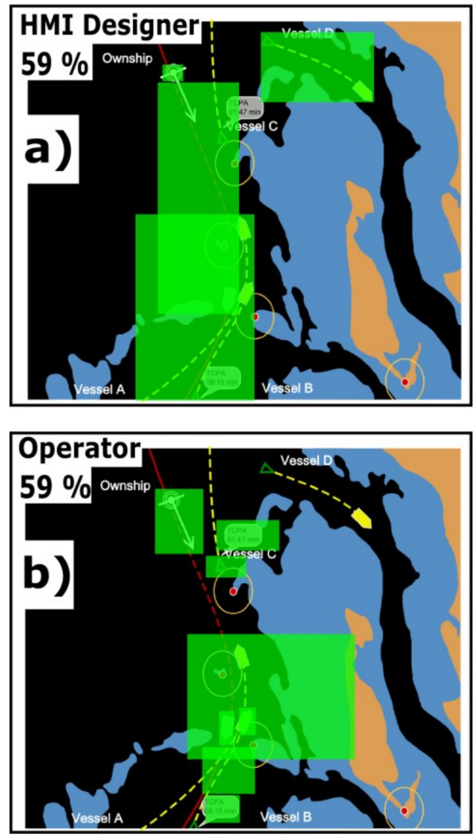


Fig. 4. IS that attract 59% of the attention as predicted by (a) the designer and (b) the operator.

2. Comparison of the designer's and operator's expectancy respectively value rating (Fig. 3a and 3b). Marked IS areas are colorized from light grey to dark grey based on either their expectancy coefficients or their value coefficients. Higher rated and overlaid IS area segments are visualized darker than lower rated ones. This enables the HMI designer SME to identify areas were the operator SME obtains information with high frequency or highly valuable information and compare it to his/her own expectations. Identically to the previous visualization all IS markups of the operator SME are shown at the same time to provide this information to the HMI designer (Fig. 2a).

3. A sequence of 100 images. Each, with the IS areas of the designer (Fig. 4a).and the operator (Fig. 4b) subsequently appearing based on the percentage of attention they capture. Those that capture most appear first. This should enable the HMI designer to identify to which ISs the operator pays attention most of the time and compare it with the ones that the HMI designer expected to capture most of the attention.

4. A sequence of figures like the one in Fig. 5. Each figure highlights one IS of the operator (blue) and one of the designer (green). The sequence of figures is generated for those ISs for that the operator predicted the most amount of attention. An automatic mapping between IS defined by the

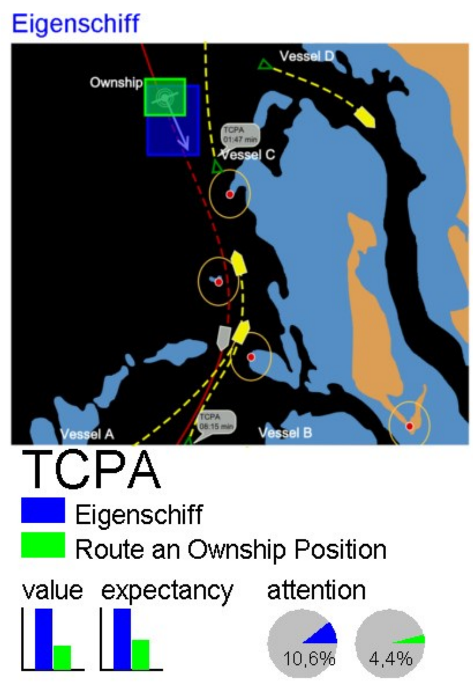


Fig. 5. Direct comparison of two IS. The IS "Eigenschiff" (engl.: own ship) defined by the operator is marked in blue. The closest geometrical match of an IS defined by the HMI designer is shown in green. The IS names, their expectancy and value coefficients and the simulated percentage of attention distributed to these IS.

operator and IS defined by the HMI designer was created based on the geometrical similarity between IS. The geometrically most similar IS of the designer is highlighted in green, so that the designer can analyze whether s/he marked the same information and whether s/he rated it as high as the operator. The respective expectancy and value ratings are shown below the figure. The geometrical similarity is calculated by the root integrated squared distance (RISD), which is sensitive to differences in size and position of two rectangles.

5. Again a sequence of figures like the one in Fig. 5. But this time the sequence of figures starts with the ISs for which only very bad geometrical matches were found, since these most likely indicate IS that have been marked by the operator, but not by the designer. This enables the HMI designer SME to identify ISs that the operator SME uses but that the HMI designer SME did not consider.
6. Finally, by applying the same geometrical matching algorithms, a sequence of figures likes the one in Fig. 5 was created that identify IS, which were marked by the designer, but most probably not by the operator.

C. *Analysis of the HMI-designers recordings*

We presented and explained the different visualizations to the designer in the order as listed above. The first four visualizations were presented to the designer for all three alternative interface designs, whereas the last two visualizations only considered the interface design preferred by the designer (we limited the session to two hours). The designer was asked to freely explore the visualization and to "think aloud". Afterwards we asked him, which visualizations he prefers and why. The entire session was video recorded. The audio track was transcribed to a textual document. Finally, the transcription was analyzed. However, the designer often commented on multiple ISs at once or pointed on regions rather than on single IS. This often led to an ambiguous text analysis. Thus the analysis was made independently by two persons:

1. It was rated whether the designer commented on the seven information elements that were previously identified important to the operator (see Section III.A)
2. For each visualization a list was created containing all ISs defined by the operator that the designer commented on while exploring the visualization. For each list entry it was rated, whether the designer gave indications, that the operator's definition of IS itself or the amount of attention predicted by the operator was unexpected for the designer (see Table I).
3. Comments in the transcription were identified, that indicate, that the designer obtained insights, which potentially help him to improve the interface design.

IV. Observations and Findings

The designer commented on all ISs that were identified as important for the operator already while exploring the first visualization (heat maps). Thus the visualizations were able to communicate all ISs to the designer, which are important for the operator.

Table I lists on how many IS the designer commented. In each cell the first number shows the rating of the first analyst and the second number the rating of the second analyst. Designer's comments were classified, based on whether the predicted attention to the IS was expected or unexpected by the designer. The last column lists the number of IS which could not be rated based on designer's comments.

It can be seen, that the designer mostly commented on ISs for which he discovered an unexpected difference to his own expectations. We observed a high amount of comments that the designer mentioned as "surprising", "very interesting", and "unexpected" that we all categorized as "unexpected" in Table I. Furthermore, for nearly all unexpected differences the designer started reasoning about, why the predictions of the operator differ from his own predictions. It seems that it was very easy for him to interpret the intentions of the operator. In only one occasion the designer explicitly stated that he disagrees with the operator's view. Though, he seemed to be aware that his interpretations are speculative, because at two occasions he mentioned that he would need to talk to the operator to confirm his interpretation. In a few cases (8) he even started to think about whether the insights that he got from his interpretations might affect the final interface design, although he never mentioned what these changes to the interface could be.

The different visualizations had a different effect on how the designer explored the predictions of the operator. The designer made comments for all visualizations. However, the order in which we presented the visualizations might have a strong effect on the number of comments.

The heat maps seem to be the most intuitive visualization, which provided a good overview. This was also mentioned by the designer after the study. The designer made a lot of comments to the visualization 2 and 3. They also present overviews of the entire monitoring interface. However, at the end of the study the designer explicitly mentioned, that

TABLE I. Number of commented IS per visualization.

Visualization	No. of IS	Expected	Unex-pected	Not classified
1. Heat maps	14 / 32	4 / 8	6 / 16	4 / 8
2. Expectancy & value ratings	22 / 16	2 / 2	9 / 8	11 / 6
3. Percentage Attention	27 / 25	4 / 3	13 / 10	10 / 12
4. Important for operator	11 / 13	1 / 2	8 / 9	2 / 2
5. Important for designer.	8 / 7	0 / 1	1 / 5	7 / 1
6. Worst IS matches	9 / 7	0 / 2	6 / 4	3 / 1

a. Designer's comments to ISs were classified as expected or unexpected. Some IS could not be classified based on designer's comments. Shown are ratings of 1st analyst / 2nd analyst.

visualization 1 (heat maps) was more helpful than the other visualizations. Visualizations 4-6 provide a detailed insight into the differences between operator's and designer's perspective, but they do not provide an overview about the entire interface but always focus on just a single IS.

We observed one case, were this focused visualization revealed information to the designer that he did not know before. The operator marked an area of the sea and labeled it "potential crossing traffic". Even so there was no port displayed on the screen, the operator concluded from the displayed geographic information that there most likely is a nearby port, from which he expects traffic. The designer was very interested in this aspect and mentioned that he was not aware, that operators interpret the geographic information in this way.

V. Conclusion

We were surprised by the amount of comments the designer made. It was obvious that the designer had no problem in deriving the operator's perspective from the visualizations. Thus, we think that the presented approach is a good way to support the communication of knowledge from operators to interface designers via a tool supported process. However, the current study was explorative in nature with only a single participant. In a subsequent step of our research we want to conduct a study with a sufficiently large number of designers and test whether they are able to derive design improvements from the predictions of operators.

Based on the result of this study, we will use the heat maps, because they provoked a lot of comments and they were the preferred visualization of the HMI designer together with one of the visualizations from 4-6 to enable a more detailed analysis. The designer commented so easily on the visualizations that we also intend to improve our tool to record these comments to support documentation and decision making processes during the HMI prototyping phase.

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