HMI Styleguide

Whitepaper: Nine Rules of Thumb for good HMI Design

Paul Winter, paul.winter@monkey-works.de
MONKEY WORKS GmbH Königsbrücker Str. 124, 01099 Dresden, +49 351 41886590

Introduction

Nowadays, almost every manufacturing process is controlled by some sort of human machine interface (HMI). This development results in operators interacting with the process mainly using one or more devices such as desktop computers, machine-mounted panels, tablets or smartphones.

Poorly designed HMIs can easily implicate serious industrial accidents. They impede operators instead of assisting them. But which characteristics distinguish a good HMI solution from a poorly designed variant? MONKEY WORKS' HMI Suite offers numerous possibilities to create user interfaces (UIs). Additionally, the UI Cruncher a tool aims at fostering good UI designs for multiple mobile platforms.

This paper is dedicated to helping HMI developers create solutions which are properly designed and implemented. And it tries to keep it short and simple.

Please note that this whitepaper is a living document. In our practical work, we face new types of problems almost every day. These experiences will be used to update or add rules in this paper on a regular basis.

What are the Advantages of Well-Designed HMIs?

Good HMIs are assisting operators in their everyday work rather than hindering them. If a critical situation occurs, the solution needs to be simple enough to allow the user to navigate to the required information or functionality as fast as possible while still providing all information crucial to the problem's solution. In fact, a lot of accidents and abnormal situations in automated environments are the result of poorly designed HMIs. For instance, a series of explosions happened in the BP Texas City refinery on March 23, 2005, with fifteen workers being killed and 180 injured. After investigating the accident, the U.S. Chemical Safety and Hazard Investigation Board (CSB), rooted the cause, inter alia, to "a poorly designed computerized control system that hindered the ability of operations personnel to determine if the tower was overfilling."[1]

> *The computerized control system screen that provided the reading of how much liquid raffinate was entering the unit was on a different screen from the one showing how much raffinate product was leaving the unit. Having the two feed readings on separate screen pages diminishes the visibility and importance of monitoring liquid raffinate in versus out, and fails to make the imbalance between the two flow readings obvious.*[2]

Furthermore, "a poorly designed computerized control system display was found to be a cause in another major incident, the 1994 explosions and fire at a Texaco plant in Milford Haven, in the United Kingdom. The control system did not calculate the material balance of the system and the operators did not know how to make such calculations."[3]

Well-designed HMI prevent accidents and save lives and protect the environment. A well-designed HMI is the result of an engineering process that includes operators, provides meaningful data, makes use of simple depictions and animations, and that makes use of standardization. A well-designed HMI is situation-aware.

Additionally, a well-designed HMI improves the UI Cruncher's understanding of the user interface (UI) resulting in a better transformation result.

[1] U.S. CHEMICAL SAFETY AND HAZARD INVESTIGATION BOARD – INVESTIGATION REPORT (NO. 2005-04-I-TX) REFINERY EXPLOSION AND FIRE.
[2] ibid.
[3] ibid.

An Example for a Bad HMI

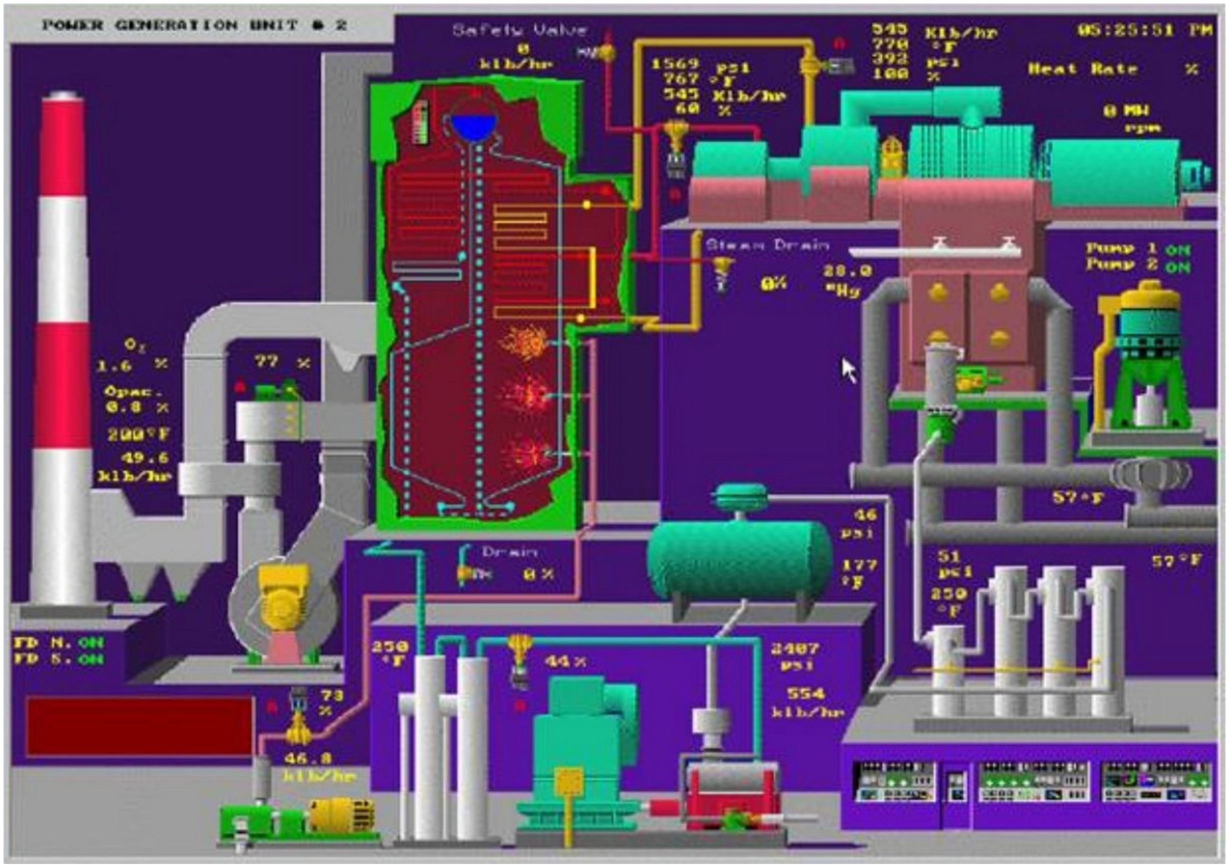

Figure 1: An example of a bad HMI [4]

Before we look at rules which help us create well-designed HMIs, let's examine an example of a bad HMI first. Figure 1 shows the UI of an HMI for a power generation facility. As you can see, the screen is full of 3D depictions of various components while the actual process values of the different components are displayed as simple numerical values next to those depictions. So while the parts which don't provide any information to the operator take up the vast majority of screen space, the parts containing the actual information are displayed inconspicuously. Additionally, all process values are displayed as simple text which do not provide any information about the value being in a normal or abnormal state. Instead, they require the operator to interpret them first in order to get this information. Furthermore, some of the depictions, for example the flames or propellers, use animations which draw the operator's attention from the important information. This results in the operator not having an overview of what is actually happening in the system, also called a low "situation awareness". Since the understanding of this term is crucial for designing good HMIs, the next chapter will explain it in more detail.

[4] Bill Hollifield, Hector Perez - Maximize Operator Effectiveness: High Performance HMI Principles and Best Practices (Part 1 of 2)

Situation Awareness? What's that?

In literature, one of the main goals of good HMI design is to increase the situation awareness (SA) of the operator using the application. But what is situation awareness? According to Paul Gruhn[5], situation awareness consists of the following three levels:

Level I: Perception of the needed data

- The operator is able to perceive the status, attributes and dynamics of the elements in his environment.

Level II: Comprehension of the current situation

- The operator is able to perform a synthesis of the disjointed Level I elements and compare them to his goals.
- The operator is able to understand how the information impacts his goals.
- This requires developing a comprehensive mental model of the system.

Level III: Projection of the future status

- The operator has the ability to project what will happen.
- This requires having a good Level II SA along with a highly developed mental model of the system.

Raising situation awareness requires understanding how humans process information. In order to design a good UI, the designer needs to be aware of the tasks and goals of the operator. A well-designed HMI supports the user by providing Level II SA rather than demanding the user to calculate the differences between the actual and the desired values. This was actually one of the major issues leading to the Texas incident described above - the operator was only provided with Level I information:

> *No single screen showed the information the operator really needed – the difference between the two – the material balance. Had this useful piece of information been presented – along with the range of values it should be, and that it had been exceeded by orders of magnitude – the conditions leading up to the accident may never have developed. The operator was completely unaware that anything was wrong.*[6]

[5] Paul Gruhn - Human Machine Interface (HMI) Design: The Good, The Bad and The Ugly
[6] Paul Gruhn - Human Machine Interface (HMI) Design: The Good, The Bad and The Ugly

Okay. So How Do I Design the Perfect HMI?

Obviously, there are various opinions on what a well-designed HMI is. This paper is compromise-oriented and tries to provide best practices based on scientific research and our practical experiences, which most authors would agree on. In the following, 9 rules of thumb for good HMI design are presented.

1. Include the Operators

The first rule is also the most important one. It is absolutely crucial to include the operators in the HMI's design process. After all, it is them who have to work with the HMI every day. According to Paul Gruhn[7], a goal directed task analysis helps identifying high level goals (not the tasks to accomplish them), cognitive processes the operators employ, their need for interaction with others, and understanding the environment where the tasks will be accomplished. Appropriate means for determining this task analysis are interviews and observation of the operator's everyday work. Additionally, an agile development process with rapid and early prototypes have proven very useful because they allow input from both designers and operators resulting in an iterative process leading to a well-designed user interface.

2. Provide Meaningful Data

A good HMI solution provides the operator with Level II SA information which helps him understand the current status of the system rather than Level I SA data which requires cognitive effort on the operator's side.

Figure 2: A UI showing the values of three process variables

Figure 2 shows a UI containing three different process values. That's fine. But are those numbers good? Are they bad? What should they be? Even if you would know the associated system perfectly, it would still take you some time to interpret the values. What a waste of cognitive effort! So how can we improve this UI?

The human brain is able to interpret graphical information much faster than textual information.[8] Actually, the respective values don't even matter as long as they are within a normal range. Try interpreting figure 3. That was much easier, wasn't it?

---

[7] ibid.

[8] Paul Gruhn - Human Machine Interface (HMI) Design: The Good, The Bad and The Ugly

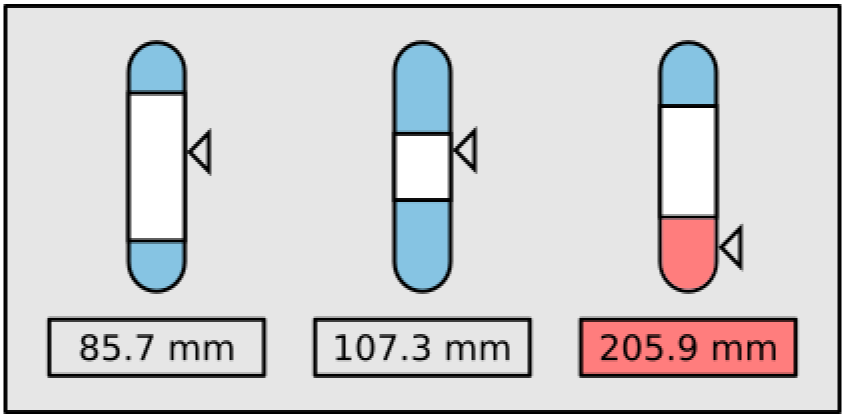

Figure 3: An improved version of the UI in figure 2

That's because the user does not need to waste energy on interpreting the current status of the system, if provided with this kind of rich information by the UI components (so-called "moving analog indicators" in this case). He can instead use this energy to predict the future status of the plant (Level III SA). Trend displays are an easy way to assist the user with this projection of the current values into the future (see Figure 4). These trend displays allow the operator to see, how the value changed over time and where it might head. This enables him to be proactive before the problem actually occurs instead of being forced to react when the problem is imminent or even already arose.

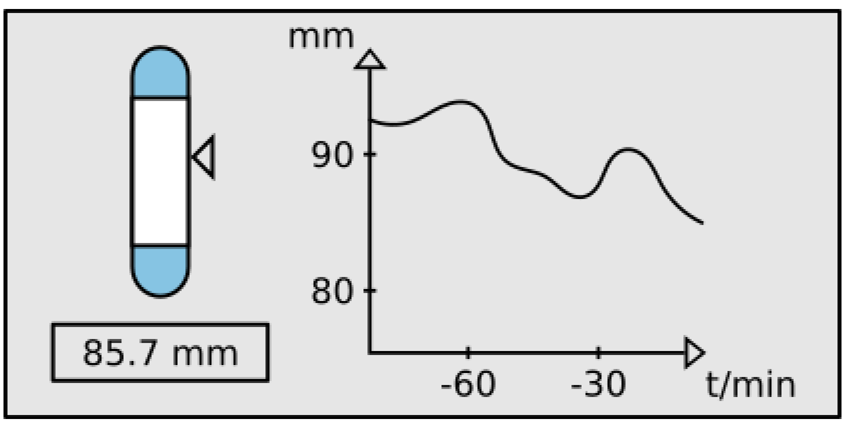

Figure 4: A more detailed representation of the first process value

Displaying this kind of rich information, of course, requires more space than displaying simple text output. Thus, not all data items can be displayed in every screen to prevent data overload. But which process variables should be displayed? In general, only critical variables should be displayed in an overview screen while less critical values such as the amperage of a normal pump in a well system should be placed on more detailed, lower level screens.

Sometimes it is hard to differentiate between critical and uncritical process variables. Even the same variables can be important for some operators and completely irrelevant for others. Take the abovementioned amperage, for example. It might not be critical for someone monitoring the water levels but imagine an electrical engineer. He does not care about the water levels but for the amperage.

Therefore, it is very be helpful to analyze the operators' workflow and include them in the design process as described in the previous rule. Sometimes, even designing more than one HMI for the same process might be useful.

3. Make the Screen Layout Easy to Understand

Early HMI designs often provided the user with so-called process and instrumentation diagrams (P&IDs) which mimic the appearance of the real plant. These diagrams were not designed to increase the situation awareness of an operator. Even if they had multiple screens, every screen displayed one section of the process of the system in great detail providing every value of every sensor in the system resulting in data overload.

Since most operators have worked in the field before, the HMI layout can support their understanding by attempting to represent the actual physical layout of the plant as much as possible without using "realistic" depictions of components and without providing too many process values. Additionally, process values should be shown directly next to the component they belong to.

Applied to a system with three tanks this means that the elements representing these tanks should be in the same order as their counterparts in the real plant. Additionally, the labels presenting the fill levels of the tanks should be placed on, above or beneath the elements representing the tanks. The labels should not be collectively shown in a different part of the screen.

Sometimes a very high level of automation can put the operator out-of-the-loop. The aforementioned rules help to maintain a high level of situation awareness despite highly automated processes.

4. Use simple depictions and animations

It may seem obvious that a simple and clearly structured UI is a lot easier to read and understand. However, there are still a lot of HMI designs not following this simple rule.

Since display systems are capable of displaying more than just text, many HMI designers take depicting equipment way too far. UIs contain spinning pump impellers, animated flames, smoking chimneys and 3D-rendered system components. These "advanced" depictions don't add any value to the UI, but do add visual distractions and can actually impede the operator's capability of understanding the current state of the process. The same applies to realistic animations. Since our focus is naturally drawn to movement, burning flames and rotating wheels distract the operator and delay the observation of critical states of the system.

5. Use colors carefully

Bright colors should generally be avoided if they don't highlight abnormal situations. Static parts of the UI should be shown in gray shades, resulting in an HMI which looks quite boring under normal conditions. An operator can easily see a flashing red element on the screen if the remaining parts of the screen use muted colors. Also, bright colors should never be used to indicate a normal state of a piece of equipment such as a regular on/off or open/closed state of a system component.

If you take a look at figure 2 from the beginning of this document again, it is immediately plain to see, that the third process variable is currently in a critical state. The red color really pops out of the screen because the other variable's outputs only use muted colors (since they are not in a critical state).

Lastly, it is essential, that colors are applied in a consistent and meaningful manner. Don't use different color codes on different screens or even within the same screen.

6. Make use of standardization

UIs also benefit greatly from standardization. This does not only mean standardizing interaction concepts, designs, the color palette and many other things throughout one HMI. The most important concepts and decisions should be applied to all HMIs of the company.

If certain elements such as menu bars or navigation elements are placed and designed in a similar way throughout all HMIs, operators will obviously need less time to become acquainted with new HMIs.

7. Develop a Sophisticated Navigation Concept

A very effective approach to represent the process is the drilldown concept which uses different levels of detail. Initially, the HMI displays a screen giving an overview of the current status of the system by showing major components along with the most important process values. Less important components of the system are not even shown on this level. In order to get a more detailed view of a specific component, the user needs to navigate to the next level down. Depending on the complexity of the system there may be more than just two levels of detail. Especially in UIs with many different levels and screens, the designer has to ensure that the number of clicks to get to any other screen is limited. This allows the operator to get to the required information in critical situations as quickly as possible. As mentioned in the previous rule, a good navigation concept should be standardized so that the navigation elements are placed in the same spot on every screen.

8. Keep the Model of the UI Structured

When it comes to modeling the UI in the HMI Suite, developing a well-considered model has many advantages. The HMI becomes easier to maintain and future changes can be applied much faster. For example, related components of the UI should be placed next to each other and they should be children of the same container. This is actually a good rule: Use container elements excessively to structure the UI. If the elements are grouped in a meaningful way, rearranging them requires much less effort.

According to Paul Gruhn[9], good UI design can be distilled down to CRAP. Oops, what? Okay, maybe that's not the best mnemonic word, but at least it is easy to remember:

- **Contrast:** Things that are different should look very different (not only regarding color).
- **Repetition:** Repeat visual elements, especially if they serve the same purpose.
- **Alignment:** Every element should have some visual connection with another.
- **Proximity:** Things that belong together should be placed together (in a common container!), those that are different shouldn't.

9. Different Devices Serve Different Aims

With the advent of mobile HMIs, a different problem arose. It is common, that more than one device type is used in order to monitor one process. But due to the different screen sizes and sometimes even other interaction modalities, it is not appropriate to implement a similar UI for all devices. Imagine all the information from a tablet UI shrinked to a smartphone version. It will most likely result in a cluttered user interface in which it is difficult for the operator to find information.

But couldn't we just split the tablet's UI pages into multiple pages on the smartphone? In rare cases, this can be the solution but most likely, the smartphone version serves a different aim. Therefore, HMI designers need to carry out a task analysis as described in the first rule not only for the process in general but for each device specifically.

Since it is not always possible on smaller devices to display each important process variable using UI components which provide rich information, it becomes necessary to strike a balance between displaying level II SA information and space efficiency. For example, not every process variable can be displayed using a moving analog indicator described in the second rule. A good trade-off would be to color the text label's backgrounds in light blue if they are within normal range and to color them red if they are in a critical state.

[9] Paul Gruhn - Human Machine Interface (HMI) Design: The Good, The Bad and The Ugly

In Practice: Revising HMIs

In this chapter, two demo applications of the MONKEY WORKS GmbH will be revised in order to make the rules defined above more tangible. All important changes will be motivated and explained in detail.

HMI: Chemical Process Plant

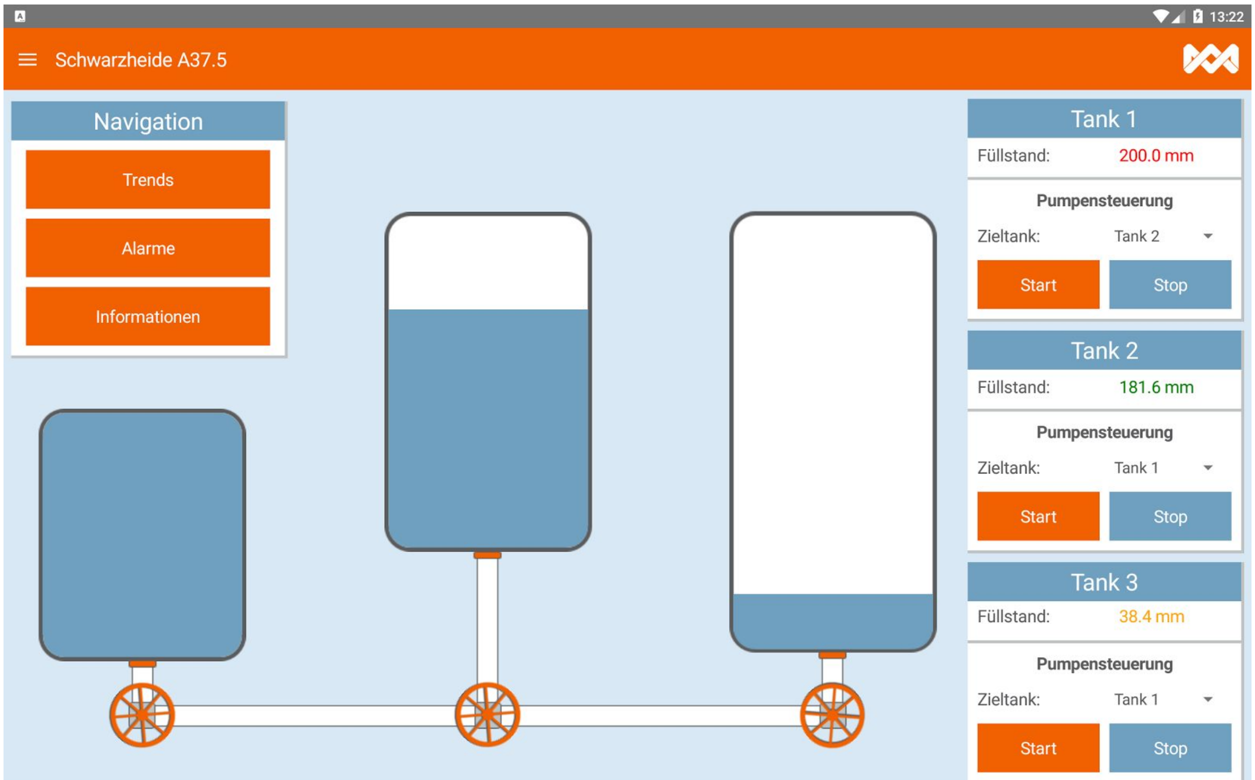

Figure 5: The old version of the chemical process plant HMI

In figure 5 the old version of the UI of an application is displayed. It shows three tanks of a chemical process plant. The HMI is used to observe the values and pump fluid from one tank to another.

So what basic principles does this industrial app violate? First of all it is obvious that rule 6 ("Use colors carefully") was not considered. The designer used the company's primary color for the title bar, buttons and various other elements although it is a signal color. The problem is that this hinders the operator from having a good SA. Just compare it to the UI in figure 6 below. Both applications have two values in a critical state. In the first example, the operator has to look at the HMI carefully in order to recognize these critical states. In the revised example, these values stand out so their state can be realized by the operator at first sight. But how was this effect achieved? Looking at the rest of the HMI, it becomes clear, that all components are designed in gray shades in order to "look boring under normal conditions" as stated in rule 6, in order to make colors signaling critical states stand out.

But there are other mistakes in the first UI. For example, the small valve wheels below each tank are spinning if a pumping process is started. As stated in rule 4, such animations don't add any value to the UI but draw the user's attention from more important information. Therefore, these valve wheels have been removed while revising the UI.

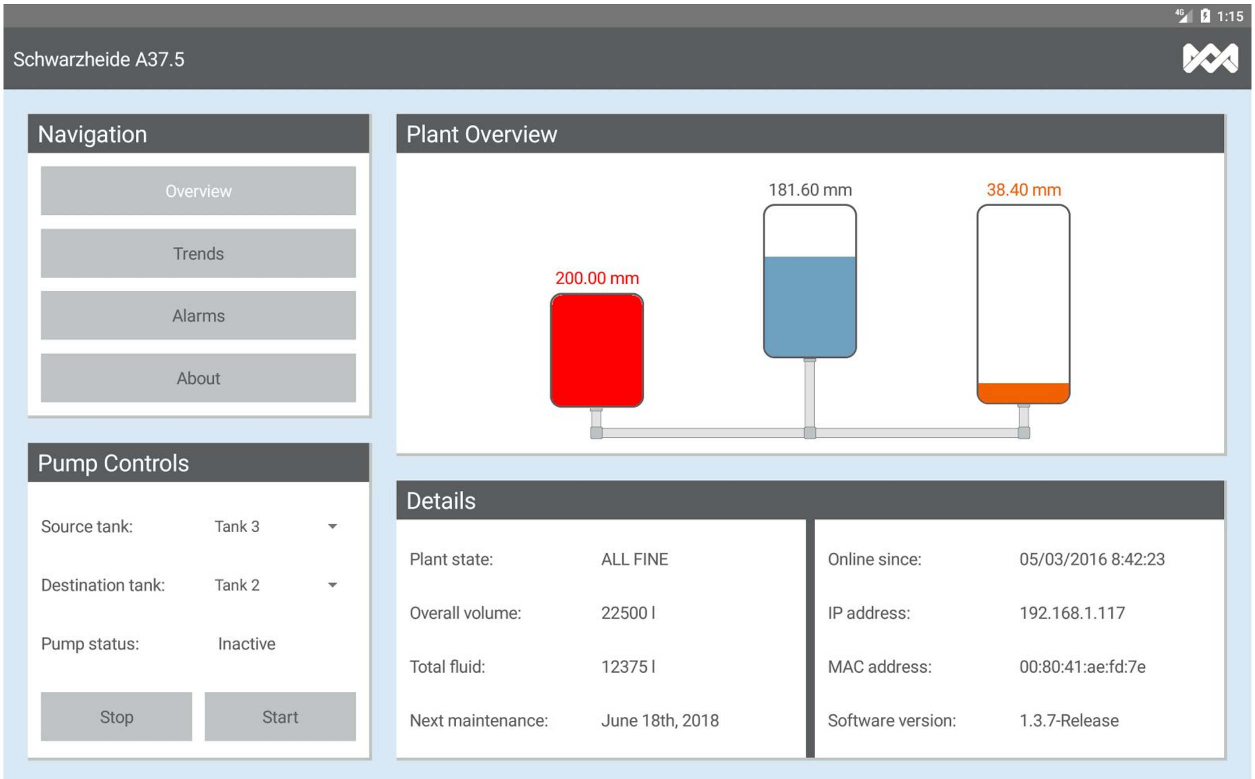

Figure 6: The revised version of the chemical process plant HMI

The next mistake which was made in the first application is that the values are not displayed next to the components they belong to which violates rule 3 ("Make the screen layout easy to understand"). It is not clear, which fill level belongs to which tank. In the second UI, the values are placed directly above the tanks they belong to. Data which is relevant for the whole plant is displayed in a box below since it does not belong to a specific component. Also, the layout of the pump controls was changed and moved in order to occupy less space while being easier to understand and use.

HMI: Wind Turbine

This HMI is used to control a wind turbine in a wind park. The current load can be observed and the turbine can be shut down and started again. The UI is shown in figure 7.

Again, the most obvious mistake in this HMI is the excessive use of color. It would be almost impossible for an operator to realize a critical value colored in red in this HMI. Also, the clouds, the sun, the daytime and the wind turbine are animated in this example UI. This again, draws the operator's attention away from the really important things. But we talked about similar mistakes in the previous example. So what new mistakes did the designer make here?

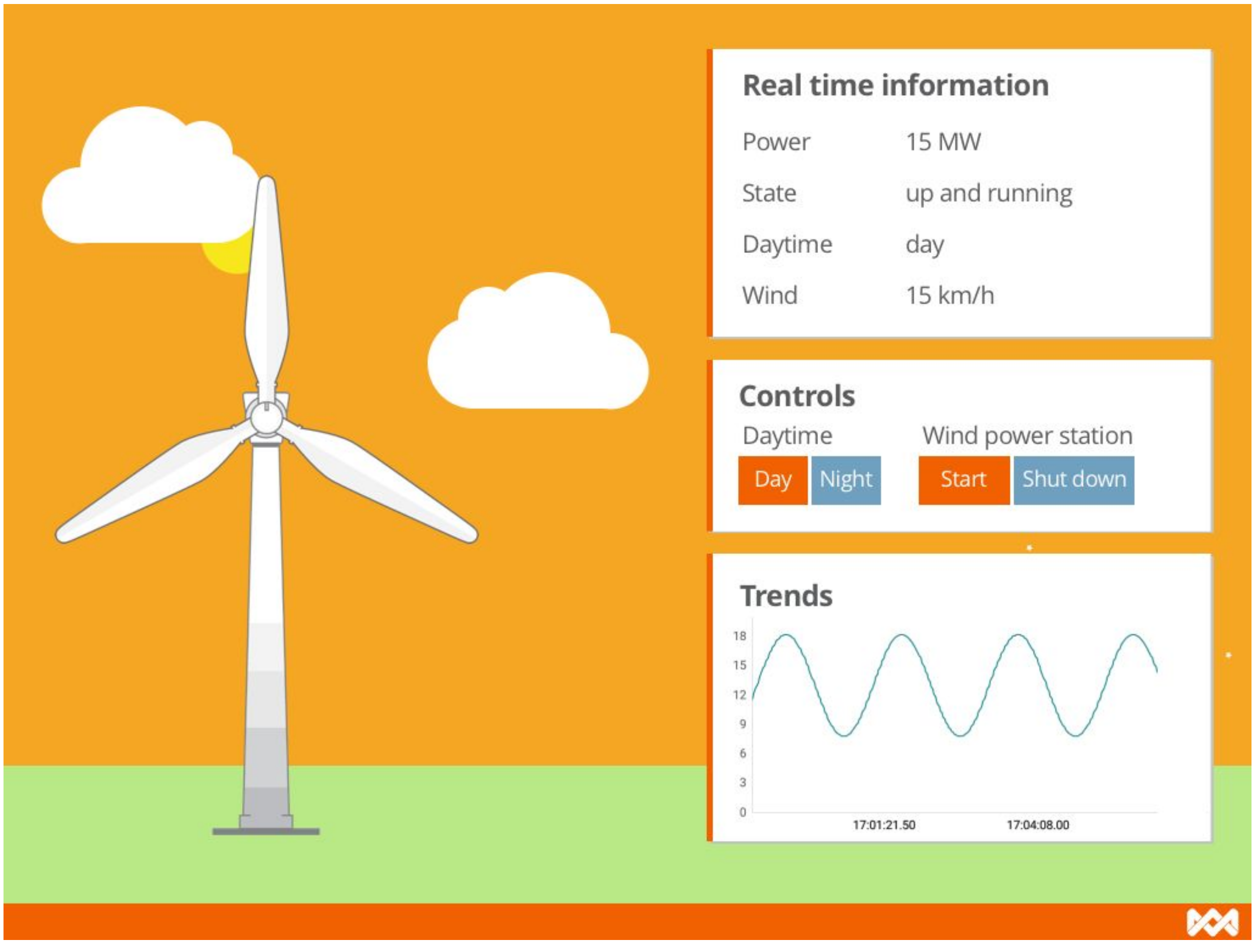

Figure 7: The old version of the wind turbine HMI

The most important value in this system is, of course, the current power load. And we can easily see that the current power load is 15 MW. But this kind of display violates our second rule ("Provide meaningful data"). The raw data is provided but the operator is not assisted in interpreting this data. Is 15 MW too high, is it too low or is it just a regular value? We simply don't know. In the revised version in figure 8 this problem was solved by using a *moving analog indicator,* as suggested by the second rule. The data is now pre-interpreted for the operator and his situation awareness is increased.

Speaking of situation awareness, the first version of the UI makes another mistake. The operator has no information regarding the state of the other wind turbines in the wind farm while looking at the details view. If another turbine would be in a critical state, he just wouldn't notice. The designer of the second UI solved this problem by using the box at the bottom right. It provides the most prominent value, the current load, for each wind turbine on the wind farm. The operator is always informed about their state and can easily navigate to the respective details view if a value reaches a suspicious or critical state.

The last thing to be pointed out is rule 6 (“Make use of standardization”). The old versions of both HMIs did not have anything in common regarding the navigation concept or basic design. For example, one has the action bar at the top, the other one has it at the bottom. Looking at the two revised HMIs, it becomes clear that they follow the same style guide. The same colors are used, the navigation menu is located in the same corner of the screen, they use similar box elements and the same background color. This makes it easier for operators to switch between different HMIs without having to adapt to a new navigation concept and design.

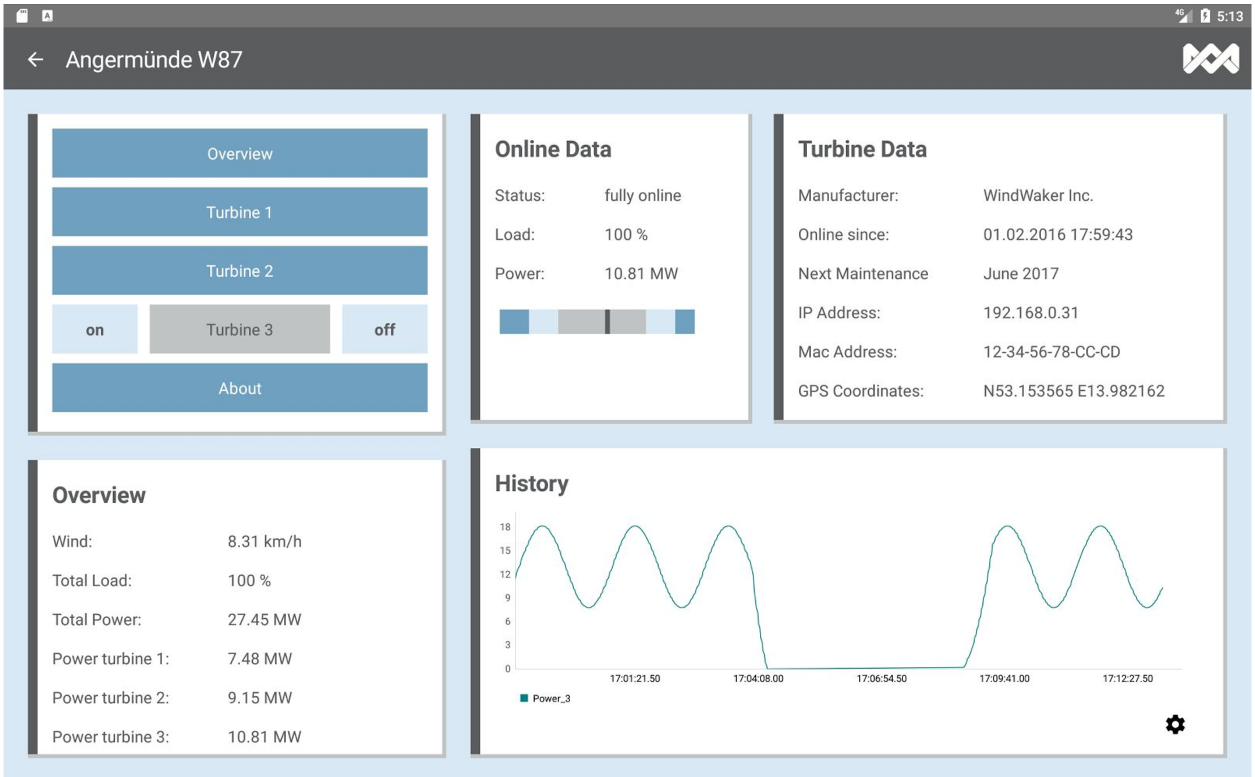

Figure 8: The revised version of the wind turbine HMI

Conclusion

Creating an HMI which just takes all available process variables and displays them on a screen is not that hard. Planning and implementing solutions which provide their operators with rich process information and assist them in achieving their tasks and goals in a proper way require much more thought. The latter type of HMIs will lead to fewer errors, higher productivity, and most importantly, increased safety.

This guide gave a short overview of the most important rules leading to such properly designed HMIs. Of course, there is much more to the subject than these rules. For more information on the topic, you can take a look at Further Reading section below.

Further Reading

- Opto22: *Building an HMI that Works: New Best Practices for Operator Interface Design,* Whitepaper, 2013.
  URL: http://www.automation.com/pdf_articles/opto_22/2061_High_Performance_HMI_white_paper.pdf

- Paul Gruhn: *Human Machine Interface (HMI) Design: The Good, The Bad and The Ugly (and what makes them so),* 66th Annual Instrumentation Symposium for the Process Industries. Vol. 25. 2011.
  URL: http://www.kirp.chtf.stuba.sk/moodle/pluginfile.php/61474/mod_resource/content/2/hmi_rules.pdf

- Bill Hollifield et al. *The High Performance HMI Handbook*. Plant Automation Services, 2008.