Human Machine Interfaces For Distributed Control Systems

Creating And Maintaining An Effective User Environment
With Efficient Graphics

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The Connected Enterprise revolves around big data. Today vast amounts of data come from manufacturing processes and The Connected Enterprise is the successful combination of manufacturing and business data. This combination creates meaningful contextual information that leads to enterprise intelligence enabling your organization to make dynamic and demand-driven decisions. It is clear that relating these data sources is important, however, analyzing and presenting big data to the modern Distributed Control System (DCS) operator on the plant floor deserves attention as well. The modern DCS operator must be able to access and understand process data, then act on it efficiently.

Business Drivers

Abnormal events continue to be significant causes of production losses and cost. The key is ensuring the operator is enabled to monitor and manage the process effectively, which includes appropriate level of situation awareness, ability to detect abnormal situations, and ability to smoothly perform operations tasks. An informed operator is an efficient operator, thus manufacturing companies have a vested interest in realizing these operator efficiencies. Additionally, responding to adverse conditions early, and avoiding costly accidents, are paramount. In many cases subpar HMI designs have been identified as contributors to abnormal situations, billions of dollars of lost production, accidents, and fatalities. Poorly designed Human Machine Interfaces (HMI) or operators interfaces, can actually often encumber the operator rather than assist them. The technological advances found in modern DCS systems coupled with industry-accepted HMI standards are driving an environment in which legacy limitations no longer apply.

Properly designed user interfaces empower operators to control their processes, while also improving:

- Safety
- Plant uptime
- Equipment utilization
- Product quality
- Task prioritization
- Prevention and response to abnormal conditions

A properly designed interface can also help reduce operator frustration and fatigue. By taking an effective lifecycle approach to HMI design and optimization, organizations can capture and transfer workforce knowledge between individuals and groups, standardizing practices and mitigating the risks associated with workforce turnover.

Challenges of Optimizing the Runtime Process Environment for Usability

Organizations seeking to improve HMI usability and performance face a number of challenges. In today's plant, operators have so much information to absorb – sometimes from multiple systems – that they've learned to respond reactively, rather than proactively. A system that forces its operators to act in response to alarms and anomalies may not allow them to actively engage with the process, and is less likely to result in optimal output.

Operator error has been cited as a major factor in many accidents. Poor HMI design leading to decreased situational awareness is considered one of many contributors to the Texas City accident.

The event involved overfilling a distillation column and a blow down vessel when no more than 10 feet of liquid were supposed to be present. The level transmitter indicated a high-level alarm, but the broken level switch did not. It was also not calibrated properly and was incapable of measuring a level beyond 10 feet.

One HMI screen showed the amount of material going into the column, another showed the amount of material going out. Thus the operator was completely unaware that anything was wrong. They could not see on a single screen the information that was required: the material balance in the column along with the expected range of values.

Legacy systems, perhaps offering fewer opportunities for HMI improvement, can also be costly to modernize, whether by upgrade or wholesale replacement. And finally, a current DCS system often has the processing and graphical capabilities to present large amounts of data to the user. However if attention is not paid to operator needs at implementation these amounts of data can be overwhelming. Standards like the ISA-101.01 seek to provide frameworks for addressing these challenges head-on.

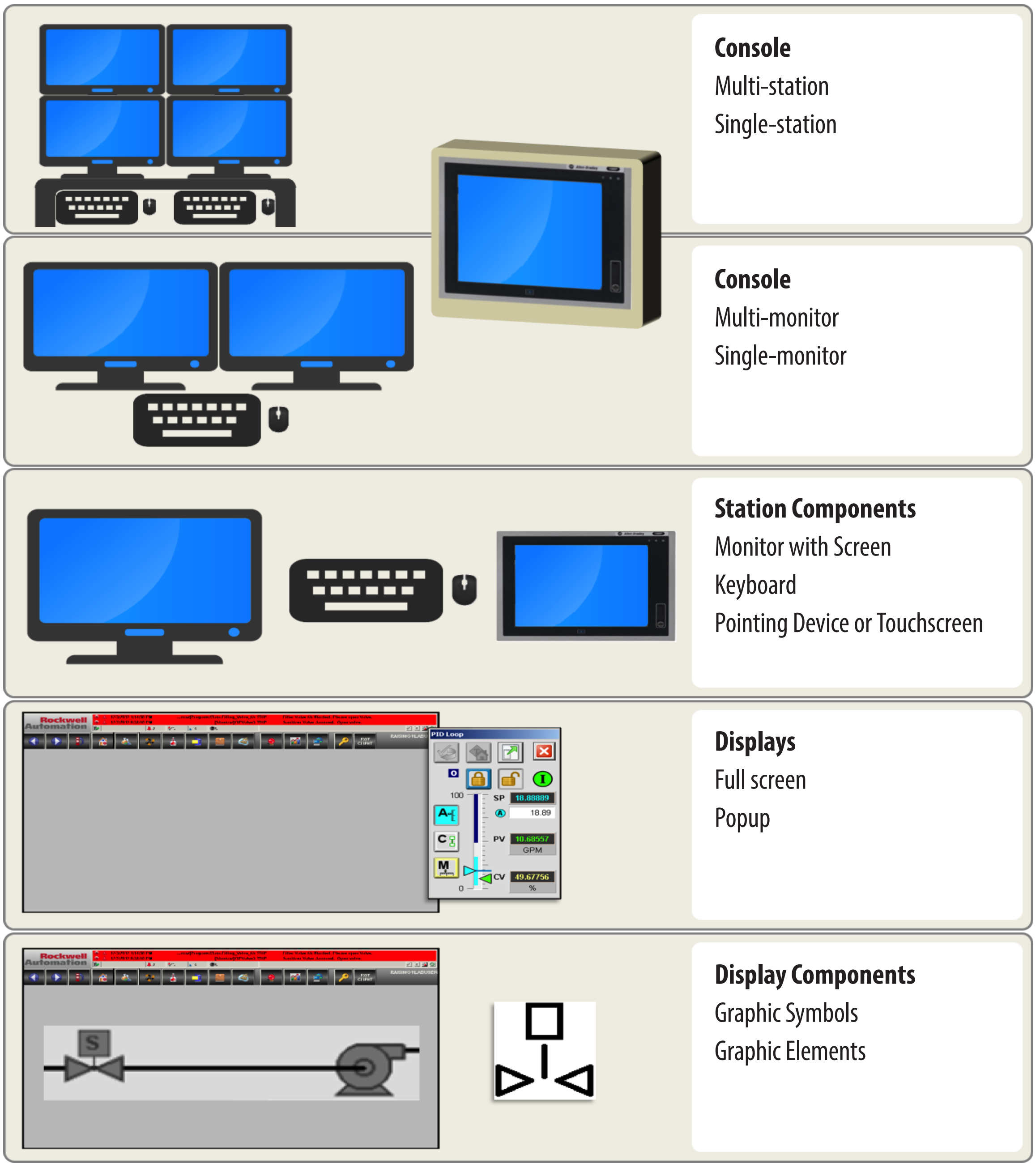


Figure 1: Selected HMI terms and their interrelationships

Overview of ISA-101.01

In order to address the need for an explicit, industry-standard approach, the International Society of Automation (ISA) formed a committee to address the philosophy, design, implementation, operation, and maintenance of HMIs for distributed control systems, including processes used throughout the HMI lifecycle. The resulting standard was published in July of 2015 as ISA-101.01. The standard contains nine clauses, with the first three addressing scope, references to other standards, and general definitions of terms and acronyms used in the standard. The remaining clauses describe best practices, mandatory requirements, and recommendations for implementing an HMI and supporting its lifecycle.

This paper will discuss best practices around human interface design aligned with the standard. It is suggested that readers have a thorough understanding of ISA-101.01 and stay current with additional work generated by ISA to help best drive these industry practices into day-to-day design and practices. A reference for selected terms used in the standard is shown in Figure 1.

HMI System Management

The core mandatory requirement of ISA-101.01 is that the HMI shall be developed and managed through a lifecycle model as illustrated in the standard. This requirement includes the creation of a set of written organization-specific system standards which include HMI Philosophy, an HMI Style Guide and HMI Toolkits. These standards should not undergo significant modification unless there is a major philosophical shift or change in project-specific requirements that calls for scope expansion. In addition to this lifecycle approach to managing organizational standards, the ISA-101.01 standard requires definition of a process to manage changes in the HMI throughout its lifecycle in order to ensure continuous adherence to system standards.

There are three clearly stated deliverables required in the system standards stage of the HMI lifecycle:

1. HMI Philosophy

2. HMI Style Guide

3. HMI Toolkits

The HMI Philosophy provides guiding principles and conceptual foundation for HMI design and use. The HMI Style Guide applies the guiding principles and concepts of the HMI Philosophy to provide implementation examples, guidance and preferred workflows for target platforms, but lacks all technical details. In general, the HMI Style Guide should provide the 'rules' for designing and building displays. These rules include the use of sound design principles derived from the field of human factors and user interface. The HMI Toolkit will be platform-specific and generates all graphical symbols and other supporting elements as required to implement the HMI Style Guide.

Once system standards have been defined for a system, ISA-101.01 identifies four steps to be followed in the design stage of an effective HMI lifecycle. The objectives of these steps are to provide hardware and software design for the console; identify the design basis for the HMI system, including selection of the control platform and related operating system and toolkits to be used; identify primary and secondary users to be supported in HMI and their tasks and requirements; and identify a conceptual design for displays and the navigation hierarchy.

The implementation stage follows the design process of a system, and ISA-101.01 identifies six steps to be followed in the implementation process for an effective operator interface lifecycle. These steps include the complete construction of displays and supporting items in the HMI; complete construction of console hardware and software, and testing of appropriate device placement and location of other elements in the system; testing of the HMI and console; training of users; and final testing and verification of the HMI system prior to moving into an operational state.

Once an HMI has been put into service, it enters the operate stage. In the operate stage, ISA-101.01 recognizes three states the HMI may enter: in service, in maintenance, or in a state of decommissioning. Once a system is considered to be in service, any changes should be handled in a manner compliant with the defined processes for management of change, including audit and, if required, validation.

Human Factors Engineering and Ergonomics

Next, the standard enumerates the underlying principles of human factors engineering and usability to provide a framework for design considerations. At a minimum, an HMI system must support the user requirements identified in the task analysis. The designer must also take into account human factors, the cognitive and physical behaviors and characteristics of the person using the tools. HMI design must take into account human cognitive and sensory limitations with respect to time, contrast, color, information density, visual dynamics, and sound recognition to provide information clearly and avoid cognitive overload. Also the HMI design should be consistent from screen to screen, so the operator can count on common denotations and it should intuitively aid the operator in situational awareness, in terms of both current and future process states.

In the last 11 minutes before the 1994 Milford Haven refinery explosion, the two operators had to recognize, acknowledge, and act on 275 alarms.

Some relevant human factors best practices include:

- Choosing screen settings (such as brightness and contrast) that are appropriate for the lighting of its location and orientation.
- Maximizing readability by using a dark, sans-serif font (such as Arial or Calibri) on a light grey background.
- Eliminating use of color except to represent anomalies or abnormal states.
- Grouping graphical objects for similar concepts or adjacent steps together (rather than representing the geographic layout of the plant).
- Avoiding animation or motion except where necessary to highlight an abnormal state (e.g. no decorative flames).

The optimized HMI assists the operator in detecting, diagnosing, and responding to deviations in the process and in correcting undesirable states of the process.

Display Styles and Overall HMI Structure

Display styles refer to how information is presented on a display or part of a display. The functional requirements of a display as determined by the HMI design process should determine the display style to be used. Display style may also be influenced by physical or technological factors such as:

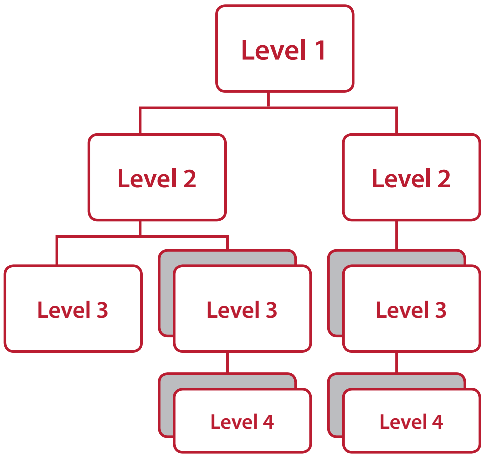
- How the user interacts with the display (touchscreen, keyboard, or mouse)
- Position of the display
- Physical size of the screen
- Quantity of information that can effectively be handled by the user

The appropriate display of information can depend on the purpose of the display, and the type of data in question. Some examples include:

- Simple list or tabular presentation of data such as operating limits or equipment lists
- Schematic display showing an overview of the process within an operator's control
- Functional overview showing the functional relationship of data
- Graph or chart displays showing trends in real time or historical data
- Procedural display of control logic, such as Sequential Function Chart diagrams
- List of status information such as an alarm summary display or message list

ISA-101.01 recommends a display hierarchy to provide a structural view of a process as noted in Figure 2. By using a display hierarchy, the designer can present an overview of a large portion of a process, without losing the ability to drill down into other displays for greater levels of detail and control functionality. Because of human cognitive limits, a maximum of four levels of displays is recommended, with Level 1 having the largest scope and Level 4 having the most focused scope.

The recommended content for each display level is as follows:



Level 1 – displays show an overview or summary of key parameters, alarms, process conditions and abnormal situations in an operator's entire span of control by being located all on one display.

Level 2 – displays are high-level process displays with more detail than Level 1 displays. Level 2 displays act as operator's primary interacting displays during normal conditions, so the scope of display can be more limited than Level 1. Level 2 displays should be task-based rather than presenting a continuous overview as in Level 1 displays.

Level 3 – displays are system detail displays that the operator uses to perform non-routine tasks such as lineup changes, equipment switching, or complex routine tasks. Level 3 displays are also task-based and should provide sufficient information for process diagnostics.

Level 4 – displays are diagnostic, they are used to provide operating procedures for a piece of equipment or help for control and diagnostics. Level 4 displays may best be presented as modal or pop-up displays, due to the brevity of information shown and the frequency of use.

It should be noted that display levels are not necessarily aligned with HMI navigation; there may be fewer or more levels in the navigation hierarchy than there are defined display levels.

HMI Display levels should not be confused with Situational Awareness Levels (i.e. the Endsley Model 1995)

User Interaction

The ISA-101.01 standard introduces recommendations for software and hardware standards for user interaction with the HMI. System-specific, high level requirements for user interaction methods should be defined in the HMI Philosophy and/or in the HMI Style Guide.

Software recommendations:

Data Entry

- Numeric entry should provide Engineering Units (EU), flexible decimals, and input limits
- When a specific input method is required, the system should enforce the proper format and should reject the value entry and alert the operator when this is not achieved
- Text select option should be provided for the recorded data
- Interaction feedback should be provided for button and command entries
- Timeout periods should be configured for a popup

Navigation

- The key design basics for navigation are performance, consistency and intuitiveness
- Common types of navigation designs include Hierarchical, Relational and Sequential

Security

- Consideration should be given to error avoidance techniques and confirmation steps for important items
- The HMI system should have some level of HMI application-specific security

Hardware Recommendation:

- HMI device selection should consider ergonomic factors
- Size consideration is based on data amount and physical spacing
- Input devices: keyboard, mouse, touch screen, voice input, scanner, buttons, switch, etc.

Performance

The standard discusses two categories of HMI performance factors:

- Performance Shaping Factors relate to how quickly an operator is able to detect, diagnose, and respond to abnormal operating conditions
- HMI Duty Factors define how quickly the HMI system responds to user actions

Rapid retrieval of process information the operator needs is important in decreasing operator reaction time in an abnormal situation.

A display should appear with live data populated within 3-5 seconds of the user request. Displays with trends or historical data may take longer, but no more than 15 seconds.

A display should refresh at twice the rate of the fastest changing data source on the display; with one second being the fastest since operators generally will not react to changes in less than a second.

Changes made by the operator should be processed by the control system and echoed back to the user in the next display refresh.

Training

The effectiveness of an HMI depends on the communication between its designer and its user. As such, the training of all parties is mandated by the standard. It should not be assumed that the documentation provided with the system is a sufficient means to transfer proper technique to the user. In addition to general navigation and functional usage of the HMI, an operator must be trained on abnormal conditions such as suppressed alarms or forced values. Ultimately the roles of the users will determine the type and frequency of the training. For example, an engineer with implementation or modification privileges should also understand the overall HMI philosophy, security, and management of change processes. Finally, management roles may also require training on how to access roll-ups or reports on HMI information.

Key Takeaways

Organizations should adopt the ISA-101.01 standard which mandates a series of best practices for HMI effectiveness.

These include:

- Optimal documentation and training on design and use of HMIs
- Consistency in usability choices including color, font, environmental awareness, hierarchy, layout, and very limited animation
- Defined display styles and hierarchies
- Optimized system performance (including response time)
- Definition of user interaction requirements for software and hardware

Options for HMI Effectiveness and Operator Efficiency

Compliance with this standard will at the very least create a high benchmark for HMI usability and performance, and optimally will provide a stepping stone for organizations to reach additional levels of efficiency. Organizations should choose to follow processes when selecting and designing their automation systems that:

- Is designed following the ISA-101.01 standard
- Empower operators to run their operation
- Includes the operator as part of the HMI design and implementation process
- Assists operators during adverse conditions
- Facilitate of new workforce members through intuitive design

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