

# MOTION DESIGN GUIDE **HUMAN-MACHINE INTERFACE (HMI)**



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# HMI Design Guide

Human-machine interfaces or HMIs (until recently called man-machine interfaces or MMIs) are access terminals on machinery, in management stations, and countless remote locations that give plant personnel and other end users a way to visually monitor and adjust automated operations, machine controls, and output functions. This human-machine interaction is through a graphical user interface (GUI) that also facilitates information exchanges between supervisory and machine-level operations.

HMI hardware traditionally integrates compact control electronics and a ruggedized display screen or touchscreen. The latter might take the form of an LCD display with tempered glass and cast-aluminum frame ... or even an LED-backlit high-definition display. In some instances, HMIs for outdoor applications or indoor plant applications with a lot of oil, dirt, and machining byproducts are built with fully sealed enclosures.

In this HMI Design Guide, Maple Systems will review these and other types of HMIs —a s well as their basic functions and new and emerging HMI functions and connectivity options. The role of HMIs in IIoT operations and the trend towards standardization will also be covered.

## Table of Contents

The origins of today’s HMIs.....	3
The most common HMI hardware variations today..	8
Complementing HMI screens.....	18
Basics of good design with HMI software .....	23
HMIs—then and now.....	32
HMIs —networking and connectivity.....	38



## The Origins of today's HMIs

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Gone are the days of machine-operator terminals based solely on switches, pushbuttons, meters, and operator warning lights. Today's HMIs control machines and monitor, analyze, and optimize operations. Some HMIs serve as the processor for I/O signals carrying feedback on speeds, temperatures, torques, tensions, and more to optimize processes. Such interfaces can help consolidate data and provide global insights based on a myriad of edge devices — those transducers, sensors, motor-mounted encoders, and other smart components (such as smart motors or smart bearings) incorporating electronics to communicate current states.

Other variations integrate HMI functionalities right into the automation devices themselves.



*HMIs can give operators detailed information on a machine's currently running cycle; send plant supervisors various statistical analyses of throughput; abolish the need for printed paper charts on facility bulletin boards; and allow managers remote access to global data from smartphones and mobile devices. In fact, many HMIs filter data upfront for its ultimate destination and authorized audience.*

Today's HMIs in discrete automation assume many of the tasks associated with distributed control systems or DCSs — considered in some industries to be a legacy control arrangement ... though still indispensable in many continuous processes.

Most leading-edge HMIs today also assume all processing of data to allow that data's presentation in human-readable graphical formats. In fact, the task of processing data for presentation in easily understood visual readouts is something the industry now mostly takes for granted.

Even in so-called lower-tech applications that base most machine-operator interactions on switches and pushbuttons, entry-level HMIs are making inroads. They often simplify controls and reduce the total part counts associated with control panels. Some such offerings on the market today are small resistive-touchscreen industrial HMIs that cost only a few hundred dollars, but still offer basic Ethernet and PLC connectivity.

On the other hand, more sophisticated applications as those on automated machinery for pharmaceutical and medical-devices benefit from the addition of **Industrial PCs** that support quality control and offer machine differentiation from competitor OEM's offerings.

We offer HMI solutions including basic HMI, IIoT edge-device HMIs, gateway HMIs, HMI with built-in IO, and powerful Industrial Panel PCs.

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HMI communication with machine controllers is also standard fare today ... and many peripheral types of hardware have yielded to software that executes communications-related tasks. Low-cost and free drivers abound. Oftentimes the main choice design engineers must make is between pre-integrated HMI panel options or the ever-more-common modular options with Ethernet and fieldbus connectivity — or the enduringly simple and cost-effective option of serial communications.

Open-source modules and easily configurable HMIs speed setup, usually by letting design engineers or machine technicians use programming software to customize the HMI. After all, HMIs by definition must be customized to the machine or operation at hand ... and comprehensively customized HMIs are the most useful. Like with other HMI manufacturers, our HMI-configuration software, [EBPro](#), and our HMI with local IO configuration software, [MAPware-7000](#), includes templates for configuring the collection of networked-machine data — and then navigation layouts to let HMI end users (on the plant floor or elsewhere) access all those data streams in a logical way.

A typical machine operator today handles an ever-increasing amount of data — and more than one person can process alone. Here, well-designed HMIs distill data to let such personnel quickly and efficiently respond to various situations ... and protect the operators and machinery from harm. In contrast, poorly designed HMI notifications can sometimes distract uninvolved

plant personnel and slowly induce alarm fatigue in personnel tasked with tending a machine — especially if the HMI throws an excessive number of warnings or irrelevant signals

Where plant personnel isn't attending to a given piece of machinery all day, HMIs can also help record and communicate what would have once been observed by sound, feel, or sight.

In contrast with legacy HMI applications (primarily focused on communicating machine status) many of today's HMIs assist operators in understanding what's normal for a given machine axis or sensor and what's not. That lets even inexperienced personnel understand and effectively act upon system-parameter values to address problems or deviations as needed. Where it's appropriate that machine operators be fully informed and empowered, that can include communication through the HMI describing potential consequences of ignoring the issue or addressing the issue with set actions.

We'll cover all these functions in this Design Guide — along with ways in which HMIs have become absolutely core components to the advancement of the industrial IoT (IIoT) and information technology and operational technology (IT/OT) convergence. This role in IIoT stems largely from the fact that HMIs are an exceptionally convenient place to integrate (among other things) plant operations with enterprise-level management.

## Human machine interface (HMI) hardware



The best HMI hardware combines ergonomics and connectivity with satisfaction of all applicable industry standards. Reliable HMI hardware also includes robust HMI firmware to ensure end users can expect glitch-free operation of the HMI's most advanced hardware capabilities.

The actual display portion of the HMI can be based on several different core technologies — and assume various physical configurations. After all, the HMI for an advanced CNC machine used to manufacture aerospace components must satisfy far different design requirements than an HMI serving as an outdoor public-transportation kiosk.

Top parameters are:

- ☒ Temperature, humidity, and exposure to dust
- ☒ Vibration of the HMI in its destined environment
- ☒ The tasks end users will need to perform via the HMI and whether the HMI will need to deliver maximal intuitiveness or if personnel will have some knowledge about the interface
- ☒ The level of danger or criticality of the design processes under the control of the HMI

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*Operator terminals (as this one from a test facility in 1942) once consisted entirely of analog control and feedback devices.*

HMI suppliers can often assist OEMs in identifying relevant industry standards (such as those defined by the FCC, IEEE, UL, or ANSI) dictating the required level of ruggedness, electrical safety, and cleanability of a given HMI.

For example, the International Electrotechnical Commission (IEC) in its IEC 60529 standard defines ingress protection (IP) codes for quantifying HMI resistance to water and dust ingress.

The Organization for Standardization (ISO) in its ISO 11064 standard defines features to ensure the “ergonomic design of control centres” on automated equipment.

The European Commission’s EU Machinery Directives define standards to ensure electrically powered equipment receiving the Conformité Européenne (CE) Mark for industrial as well as consumer use pose no electromagnetic interference (EMI) issues. The same organization’s ATmospheres EXplosible (ATEX) standards provide rules for ensuring safety in potentially explosive settings involving flammable chemicals such as petrochemicals as well as flour and sawdust. Yet other standards are specific to geographical regions and transportation, semiconductor, packaging, and medical markets.

Read more about occupational safety standards that dictate the specifics surrounding some HMI features in this guide’s section on HMI software and GUIs.

# Human machine interface (HMI) hardware

X	NO RATING
0	NO PROTECTION
1	PROTECTION AGAINST SOLID FOREIGN
2	PROTECTION AGAINST SOLID FOREIGN
3	PROTECTION AGAINST SOLID FOREIGN OBJECTS
4	PROTECTION AGAINST SOLID FOREIGN
5	PROTECTION AGAINST
6	DUST TIGHT

X	NO RATING
0	NO PROTECTION
1	PROTECTION AGAINST VERTICALLY FALLING WATER DROPLETS • LIMITED
2	PROTECTION AGAINST VERTICALLY FALLING WATER DROPLETS WITH ENCLOSURE TULTED UP TO 15° FROM
3	PROTECTION AGAINST SPRAYS UPTO 60° FROM VERTICAL • LIMITED
4	PROTECTION AGAINST WATER SPLASHED FROM ALL DIRECTIONS •
5	PROTECTION AGAINST WATER JETS •
6	WATER FROM HEAVY SEAS OR PROJECT-ED BY POWERFUL JETS SHALL NOT
7	PROTECTION AGAINST THE EFFECTS OF IMMERSION IN WATER BETWEEN 1 CM
8	PROTECTION AGAINST THE EFFECTS OF PRESSURIZED WATER SUBMERSION FOR
9	PROTECTION AGAINST HOT HIGH-PRESSURE WASHDOWN (AS EXPERIENCED BY CONTROL PANELS OR ELECTRICAL EQUIPMENT IN PHARMA-
9K	PROTECTION AGAINST ALL INGRESSEVEN UNDER HOT HIGH-PRESSURE WASH-DOWN (AS EXPERIENCED BY VEHICLES

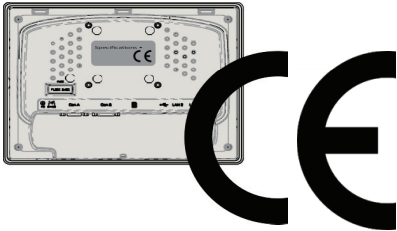
One option for OEMs looking to upgrade moderately sophisticated machines is to pre-integrate a mid-range HMI. The caveat here is that most HMIs directly mounted to machine frames must be ruggedized — with a plastic or even an aluminum enclosure to withstand exposure to water, vibration, and dust. Learn more about our HMIs, including our Class 1, Div 2 [HMIs with local IO](#).

IEC 60529 INGRESS (or more properly)

INTERNATIONAL PROTECTION (IP) RATINGS

FIRST NUMERAL INDICATES PROTECTION AGAINST SOLID FOREIGN OBJECTS

SECOND NUMERAL INDICATES PROTECTION AGAINST MOISTURE



The Conformité Européenne (CE) Mark for industrial HMIs indicates that the component poses no electromagnetic interference (EMI) issues.



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## The five most common HMI hardware variations



*HMI hardware often integrates compact control electronics and usually a ruggedized display screen or touchscreen. The latter might take the form of a liquid-crystal display (LCD) with tempered glass and cast-aluminum frame or a backlit light-emitting diode (LED) high-definition display.*

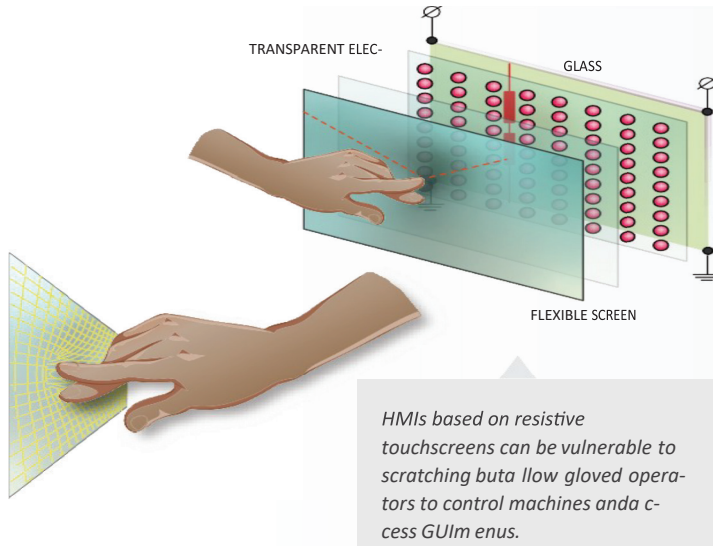
*In some instances, HMIs for outdoor applications or indoor plant applications with a lot of oil, dirt, and machining byproducts are built with fully sealed enclosures as well.*

## HMI HARDWARE OPTION ONE OF FIVE: RESISTIVE TECHNOLOGIES

HMIs based on resistive touchscreens employ one of two thin-film-transistor (TFT) liquid-crystal (LCD) options. Relatively simple to setup, they let machine operators have intuitive interactions with the machine. In short, resistive touchscreen technology senses physical flexing of the touch surface. Twin conductive screen layers (both transparent) having uniform resistance over their entire areas are separated by a minuscule distance. Upon the application of pressure (say, from an operator's finger) the outer layer flexes into the inner layer at that location ... and that in turn causes electricity conduction that's detected by the screen's onboard electronics. This mode of operation means operators (in packaging and medical settings, for example) don't need to remove their gloves to interact with the resistive-touchscreen HMI ... and can use a stylus to interact with the HMI screen if that's preferred.



In fact, resistive touchscreens are quite common in industrial HMIs for two additional reasons: They're very cost effective and quite resistant to dust, moisture, and an array of common chemicals. The only caveat here is that they can be susceptible to scratching if end users use sharp objects to interact with the screen.



Maple Systems offers HMIs, HMIs with local IO, and Industrial Panel PCs with Resistive touchscreen technology. Ranging from 4.3" to 21.5"



Example of a Resistive Touch HMI from Maple Systems:

HMI51000B: 10.1" HMI, Touchscreen, 1 Ethernet Port, 1 USB Port, 2 Serial Ports 1024x600 Resolution, CE, RoHS, IP65, Remote Access.



Example of a Resistive Touch Industrial PC from Maple Systems:

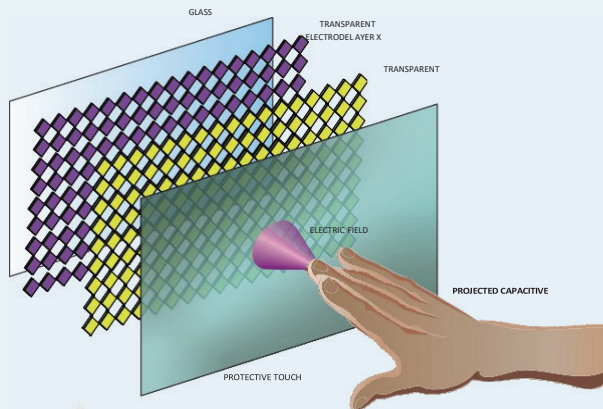
OMI6808B: 8.0" Industrial Panel PC, Intel Pentium® N4200 1.1GHz CPU, Windows® 10 options, Fanless, Rugged Enclosure. 4GB RAM, 2 Ethernet Ports, 2 USB Ports, 2 Serial Ports, 1 Audio Out, Optional Wi-Fi

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## HMI HARDWARE OPTION TWO OF FIVE: CAPACITIVE TOUCHSCREEN DISPLAYS

Besides resistive touchscreens, capacitive touchscreens are the other thin-film-transistor (TFT) liquid-crystal (LCD) option. This is the technology inside iPhones and most of today's consumer mobile devices. Industrial HMIs employing capacitive touchscreen technology have proliferated in recent years as the technology has become increasingly affordable ... so that in fact, current trends are seeing industry adoption of capacitive touchscreens outpacing that of resistive displays.

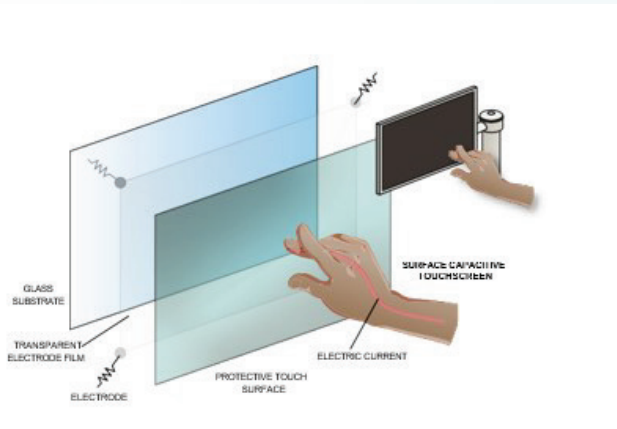


*There are two different types of thin-film-transistor (TFT) liquid-crystal (LCD) capacitive touchscreen options for industrial HMIs. Their adoption has expanded HMI use in industries needing bezel-free designs, mostly because they help machinery meet cleanliness and sterility requirements. In addition, capacitive touchscreens extend field life — because they don't use on-display pressure points of form the circuit, so they're not vulnerable to the wear and decreased sensitivity some resistive displays exhibit.*

### Capacitive touchscreens come in two subtypes:

Surface capacitive touchscreens (the older of the two versions) have a transparent yet conductive electrode layer (sometimes called the electrode film) under an insulator layer. A small voltage on the conductor layer generates a uniform electrostatic field. Then upon intrusion of some conductive object upon the insulator layer's outer surface (whether a machine operator's finger or capacitive stylus) voltage on the electrode layer drops around the area of contact.

Projected capacitive touchscreen (PCT) HMIs are the newer option — and the technology that allows multi-gesture functions. This technology also incorporates a conductor layer that normally carries a uniform electrostatic field — that is, until some conducting object touches the insulator surface and causes a voltage drop. However, this technology also has a second electrode layer with its rows of electrodes at 90° to the first layer’s rows. Together the two row sets make a grid of intersecting electrodes that can register gestures that the HMI’s onboard electronics recognize as swiping, zooming, and pinching.

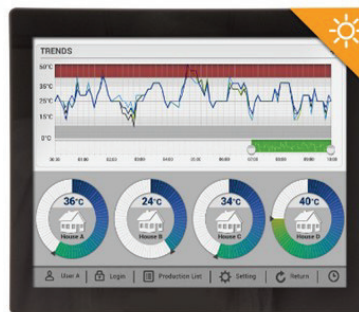


Maple Systems offers [HMIs](#), [Industrial Panel PCs](#), and [Industrial Monitors](#) with Capacitive touchscreen technology. Ranging from 15.6 to 21.5”.



Example of a Capacitive Touch HMI from Maple Systems:

[cMT3152X](#): 15.0” Smart HMI, Projected Capacitive Touchscreen, 2 Ethernet Ports, 1 USB Port, 2 Serial Ports. 1024x768 Resolution, CANBus, UL, CE, RoHS, IP66, Remote Access.



Example of a Capacitive Touch Industrial Panel PC from Maple Systems:

[PC1317PBH](#): 17.0” High Brightness Panel PC, Intel® 7th Gen Core i5 2.6 GHz, or i3, i7 CPU options, Windows® 10 options, Fanless.

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## CAPACITIVE TOUCHSCREEN DISPLAYS (continued)

That in turn allows full use of all graphical elements on the HMI's screen. For example, a full-hand five-finger pinch might always return the user to the HMI homescreen. Three-finger swipes might rotate the HMI screen through various menus — eliminating the need for icons on the homescreen to flip through them. Swiping upward from the HMI's display bottom might pull up a global-settings menu.

Complementing this gesture recognition in many PCT-based HMIs are haptic feedback features — those rumbling, pulsing, and vibrating sensory-feedback features that give machine operators instinctually registered confirmation that the HMI recognized the touch commands.

Capacitive displays are particularly helpful in medical and food-and-beverage applications that need bezel-free designs, as they're maximally sleek to let personnel more easily clean and even sterilize machinery (including the HMI). The glass surfaces of capacitive touchscreens (with material-science advances making these more robust than in the past) further enhance cleanability and chemical resistance ... as well as display resolution and clarity.

Solid-glass capacitive touchscreens also tend to last longer than HMI hardware based on resistive technologies, because the screens don't rely on the application of pressure points to form circuits for operation — so don't tend to wear out exhibit diminished sensitivity over time. Plus their screens are less prone to damage from an impact than resistive-based screens ... and not prone to scratching and damage from scratchy cleansers, surface contaminants, or liquids.

All this said, it bears repeating that the most significant benefit of capacitive-touchscreen HMIs is almost universal user familiarity with the technology's operation ... partly because capacitive-touchscreens are inherently intuitive to use and partly because they've become so familiar due to their abundant use in consumer electronics.



Check out the [YouTube video](#) detailing how Maple Systems now offers HMIs with sophisticated capacitance-based gesture controls. For example, [cMT3162X](#) full-HD HMIs offer stunning clarity and haptic feedback in the form of vibrations when onscreen buttons are pressed. That feedback is useful on loud factory floors where other confirmational feedback such as beeps may go unheard.

## HMI HARDWARE OPTION THREE OF FIVE: NO SCREEN AT ALL BUILT INTO- THE HMI



Our [Headless HMIs](#), with or without an attached [monitor/display](#), offer flexible installation options.

Another newer HMI option that's only been on the market for a decade or so is that having no built-in screen at all. These units are sometimes called faceless HMIs, headless HMIs, screenless HMIs, virtual HMIs, and (in some formats) DIN-rail HMI modules. We also offer Industrial Box PCs that can operate with or without a display/monitor. Such HMI options communicate their data to human personnel and higher-level enterprise systems in a few ways.

Our [headless HMIs](#) and [Industrial Box PCs](#) can connect to the internet via Wi-Fi for data communications to authorized smartphones and tablets. One caveat is that such functionality necessitates device-appropriate GUIs to present real-time machine information in easily comprehended diagrammatic, schematic, and text combinations. The more customized such GUIs are, the more useful these HMI GUIs tend to be.

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## Headless HMIs (continued)

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In other cases, headless HMIs connect to large commercially available industrial monitors through a standard HDMI cable. Usually, these arrangements are reserved for times when management needs to mount a large screen to a plant's ceiling as a way to prominently share pertinent data with plant personnel about a line's throughput — or a specific machine's status or warnings.

In still other installations, headless HMIs connect to industrial PC-based controls that communicate pertinent data to those who require it. Sometimes that lets multiple users (including maintenance technicians, supervisors, operators, and company owners) concurrently access a given machine's data — each getting his or her own datasets in formats that are most useful their particular role at the organization ... and not just a mirror of what a machine operator might be seeing on a locally connected display or monitor.

Benefits of headless HMIs abound. At less than a thousand dollars for standard offerings, they are more cost effective and appropriate than traditional HMI options involving underutilized local screens. Headless HMIs also let machine operators tend multiple machines at once — and carry a mobile device to monitor and command machines as needed.

Example of a headless HMI options from Maple Systems:

[CMT-SVR-100](#): *Smart Server, Headless HMI, Serial to Ethernet Server.* 2 Ethernet Ports, 1 USB Port, 1 Serial Port, Remote Access .

Connect various serial and Ethernet devices, and provide remote access via phone/ tablet/PC.

See all our [headless HMIs](#) and [Industrial Monitors](#).





A related benefit is how such HMIs let maintenance personnel walk around and more efficiently troubleshoot very large machines that may be having issues with misbehaving sensors, switches, motors or other components on subassemblies that are adjacent to the HMI screen. In contrast, traditional setups station the HMI at one location and force maintenance personnel to inefficiently run between it and different parts of the production line during their troubleshooting work.

With today's technologies, we can help you connect your many plant devices to create your own large Andon Board or Status Display Station, monitoring equipment and production status with a large mounted display.



Another example of a headless HMI from Maple Systems, the [CMT-FHDX-220](#) with HDMI video-out to a [monitor or display](#) can create an Andon board to monitor KPIs, status and alarms, production lines, and more.

*“Thanks to new forms of HMI connectivity, end users today can use portable consumer electronics (and their advanced displays, wireless communications, and processing power) to monitor and control machines.”*



Maple Systems' headless HMI support fully distributed system access – to let personnel monitor and control automated systems through their tablet or smartphones. Such connectivity can allow multiple users with different job functions to concurrently access a given machine.

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## HMI HARDWARE OPTION FOUR OF FIVE: OPEN SOURCE HMIs (Industrial PCs)

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A common HMI variation now taken for granted are those built around Industrial PCs. In fact, it's astounding how most design engineers today would likely define HMIs to be self-contained Industrial PCs or equivalent fanless electronics based on a single circuit board running Linux or other operating system (OS). Such Industrial PC components are more complicated and costlier than some alternatives due to their inclusion of more electronics and software resources. Nevertheless, they've become standard components over the last 20 or so years — executing (in traditional setups) the HMI and PC-based machine controls on a common microprocessor. The last few years have even seen new Industrial PC iterations with dual and even quad-core processors (1 and 1.6-GHz) for the benefits of an integrated system but segregation of HMI and control functions for real-time handling of advanced motion and automation tasks.

No matter the exact PC electronics, HMIs built into PC-based systems are part of a multi-function design. In many cases, that makes it possible to expand system functions as needed. Later in this guide we will detail how some such HMI systems often deliver capabilities beyond machine control — including digital and analog I/O-based integration into automated factory and enterprise-level systems.

The assumption of control functions is a natural progression of HMI technology, as traditional PCs are all based on a centralized processor hosting an OS that manages attached resources — including memory, external communications, and (most significantly to this topic) visual display. That means employing a PC already in the system to manage an industrial screen incurs no additional cost. When suppliers manufacture the PC components to fit into a flat format, this imparts yet another benefit ... namely, a streamlined and economical amalgam component with a single housing and mount.

Industrial PC products also facilitate efficient fault and diagnostic messaging, adjustments of machine functions for maintenance and repair tasks, and network communications. No wonder Industrial PC products that combine a touchscreen with control electronics have become so common

*Maple Systems offers [Industrial Panel PCs](#) in sizes ranging from 7.0" to 21.5".  
Or pair one of our [Industrial Box PC](#) with one of our [Industrial Monitors](#) for maximum flexibility.*



## HMI HARDWARE OPTION FIVE OF FIVE: LCDs IN OIT-TYPE HUMAN INTERFACES

Not impressed with how advanced HMI hardware has become in recent years? The use of touchscreens throughout the world in commercial and industrial settings as well as our personal lives can make it difficult for younger engineers in particular to grasp the significance of leading industrial touchscreen HMI formats today.

What can illustrate modern HMIs' significance is a brief discussion of other options that once competed quite a lot with HMIs ... and continue to do so in simple applications. This technology is an HMI hardware alternative called an operator interface terminal or OIT. In some contexts, these are lumped into the general component category of HMIs. Maple Systems has been, and continues to, manufacture our own OIT series. Made right here in the USA.

The most common OITs still sold today consist of a small aluminum housing containing electronics and an alphanumeric keypad (with 16 or 24 keys, for example) complemented by a small rectangular non-touch display. The latter is usually a liquid crystal display (LCD) or vacuum fluorescent display (VFD). Most OIT displays are bright monochrome variations capable of showing two or four lines of simple text (to 20 or some other number of characters) or numerical values related to machine functions.

OITs typically integrate modest processing electronics though rely on the controls (such as a PLC) to which they're connected for advanced functions. Communications sometimes occur through an RS-232 connection; then the OIT receives programming via this interface along with manual entries via the alphanumeric keypad. In some cases, programming is simple American Standard Code for Information Interchange (ASCII) text in and out.

Our OITs feature user-definable keypads and work with countless motion controllers, embedded microcontrollers, and PLCs from Mitsubishi, Yaskawa, Emerson, GE, Koyo, Schneider, and other component suppliers for dedicated functions.

*Examples of OIT from  
Maple Systems with LCD  
or VFD displays, and  
programmable keys.*



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## Complementing HMI screens: Modern versions of traditional tactile-control components

Many HMIs are installed on control panels and complemented by pushbuttons, switches, keylocks, ruggedized keyboards, and dials. That's because all HMIs (even touchscreen HMIs) have limitations. For example, a traditional mushroom-head emergency-stop button that can be slapped by an operator during a true emergency is far superior to an e-stop hiding on an HMI's homescreen.



As mentioned, the term HMI (depending on the context) can refer to anything from a simple instrument panel with a smattering of basic switches to a profoundly sophisticated IIoT module employing software and hardware to unify all the modern systems of factory automation—including superimposed systems such as supervisory control and data acquisition (SCADA) systems, manufacturing execution systems (MESs), and enterprise resource planning (ERP) systems as well as cloud services. In this guide we use the term HMI as industry most commonly uses it today—to refer to those singular pieces of hardware that either integrate or connect to some type of visual display screen ... with or without more advanced IIoT functionality.

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**Another broad definition of HMIs used in some contexts encompasses control panels complete with pushbuttons and switches. We restrict the use of HMIs to indicate those components associated with some graphical display of machine information and control options.**

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With these definitions in mind, let us now consider the more integrated control panels (sometimes called machine front panels) into which some visual-display HMIs integrate. Such panels can include the HMI as well as electromechanical pushbuttons, switches, analog (potentiometer) dial selectors, keylocks, ruggedized keyboards, and toggles — sometimes called discrete tactile-control components — for various modes of human-machine interaction. Today many such tactile-control components (as well as analog indicators, LED signal towers, and sound alarms — beyond the focus of this guide) network into systems via serial bus connections. Most are fairly mature designs, so register modest currents and voltages but are quite reliable.

Another item to note here: Some suppliers of discrete tactile-control components call these components actuators, but we avoid that term to prevent confusion with linear and rotary electric-motor-based actuators in the motion systems of automated machinery.

Machine builders selling into high-tech industries such as pharmaceutical and medical-device manufacturing have replaced as many control-panel components as possible over the years with advanced HMIs capable of serving the same functions. That's especially true where OEMs have recognized advanced HMI features may (despite their cost) still trim overall control-panel expenses by lowering part counts and the need for wiring many different discrete items. But all HMIs (even advanced touchscreen HMIs) have limitations. For example, a traditional mushroom-head emergency-stop button that can be slapped by an operator during a true emergency is far superior to a virtual button lingering on an HMI's homescreen to prompt the same machine shutdown — and in fact, the presence of such mechanical e-stops on moving machinery is usually required by law.

In addition, plant personnel who must wear gloves may find mechanical buttons and selectors preferable to capacitive-touchscreen HMIs. That's especially true where such HMIs would otherwise require a high sensitivity setting — and annoyingly respond to the approach of an unexpectedly ungloved hand with some inappropriate reaction before the operator makes actual screen contact. Equally inconvenient is how some resistive-touchscreen HMIs tend to wear, haze, and get scratched in outdoor or dusty settings. Plus, while expert plant operators may be intimately familiar with HMI GUIs on machines that they monitor every day, passive or novice personnel may also find electromechanical controls more intuitive. That's especially true where a panel device has only one clearly labeled function.



Read our article on how to [Upgrade your Legacy System for the IIoT with our Communication Gateways](#) and Edge Devices.

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## Complementing HMI screens

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In fact, the inclusion of pushbuttons and other electromechanical elements on a control panel can also eliminate the problem of false triggering associated with resistive-based touchscreens and possible with capacitive-based touchscreens as well. These false triggers can arise from the presence of water droplets, EMI from adjacent power supplies or machinery, and certain kinds of debris. Yet another benefit of electromechanical tactile-control components is that most don't glow as brightly as HMIs — so can be safely located on control panels in automated mobile equipment that's shouldn't distract or compromise a driver's low-light vision.

As mentioned, having lots of discrete tactile-control components on a control panel involves copious wiring. That's why suppliers of these components have in recent years made them:

- ☒ More compact for tighter spacing on control panels
- ☒ Feature at their rears either tapered screw-down wire receptacles or (increasingly common) spring-loaded push-in wire receptacles for lightning-fast and unbeatably reliable integration
- ☒ Available in versions with gasketed snap-in construction — to let panel integrators quickly insert them into pre-machined openings (in some cases sans keyways) on the control-panel face during machine assembly

Suppliers have also made tactile-control components more customizable in recent years with plentiful lighting, color coding, and texture options. Consider one tactile-control panel component that perfectly complements HMIs — softkeys. These are mechanical buttons aligned to the sides or bottom of the HMI screen that are programmed to perform various functions depending on what the HMI screen is displaying.

Or consider piezo pushbuttons, another tactile-control component that's come to offer machine builders a fresh new control-panel option in recent years. These solid-state switches are vandal proof and rugged enough for standalone smart designs such as parking meters and outdoor ticketing kiosks. However, they're also found alongside HMIs on control panels in industrial settings. Just like their traditional electromechanical pushbutton counterparts, these piezo pushbuttons come in standard 16, 22.5 (most common) and 30.5-mm diameters — essentially to accommodate the average size of a human fingertip.



In short, these switches contain in a one-piece housing (usually of stainless steel) a piezo subcomponent directly underneath a depressible surface that's thin enough to deform upon the application of normal human finger force. The generated signal's pulse width is dependent on the applied rate of force change, so quick finger taps are actually the most reliable way to activate these switches. (Electronics internal to the switch convert the piezo subcomponent's charge output into a usable control signal.) No wonder such switches are found alongside HMIs with IEC 60529 International Protection (IP) ratings for machinery in aerospace, food and beverage, and medical-laboratory settings. The switches' resistance to corrosion and heat also allows their installation closer to ovens and commercial dishwashers than HMIs.

Of course, piezo pushbuttons are just one component that can complement HMIs. Traditional electromechanical pushbuttons remain absolutely essential control-panel switch components thanks in part to dead-simple operation, efficiency, and ruggedness — even to IP69K for the hot high-pressure washdowns of food processing, for example. Finger depression or other mechanical activation essentially causes a small displacement of internal contactors that close a circuit ... so the switch generates an output signal in response to any sufficient input-force magnitude.

Some electromechanical pushbuttons qualify as short-travel tactile control components. All short-travel components include an activation surface designed to deflect a small yet physically satisfying amount — usually about 1 to 4 mm or so, with the switch or other electronics typically actuating when the input is displaced about halfway. The relatively low profile of such construction (especially when the tactile-control device is gasketed or membraned) makes the control panel easier to disinfect — which is paramount in meat processing plants and operating rooms, for example.

The human-detectable physical displacement and the audible click (and force) at the end of stroke also serve as simple haptic feedback for machine operators. In contrast, piezo-based pushbuttons also sport a low-profile construction that facilitates washdown ... but have deflection surfaces that are displaced just a tiny percentage of this multi-millimeter stroke. That's why many integrate LEDs that illuminate upon activation ... to give machine operators activation confirmation.

Other short-travel tactile control components besides electromechanical pushbuttons are computer mice and keypads with dome-shaped keys (protected by an overlay) or conductive rubber keys.

## Complementing HMI screens

We've already mentioned mushroom-head emergency-stop buttons ... and in fact, regulations established by regional, international, occupational, and industry entities mandate that emergency stop switches be conspicuous and triggered by mechanical (not solid-state) action of a circuit with a direct safety-grade connection to machine controls. Another safety-related component that complements HMIs is the keylock switch. These can prevent unauthorized users from starting an expensive or dangerous machine — and accept (and record use of) several different mechanical key versions granting various levels of machine access.

One final class of discrete tactile-control components are those for directly commanding (with manual hand control) one or more motor-driven motion axes. These components include joysticks, trackballs, and touchpads through which trained machine operators steer the motion of a robot or other powered machine. Joysticks are a leading choice here, as they allow use of myriad analog and digital signals, actuation forces, and controls (even over multi-axis arrangements) as well as various morphologies to satisfy design objectives related to ruggedness, ergonomics, and (for sophisticated applications) tactile feedback.



# Basics of good design (and configurability) with HMI software



Software related to the graphical user interface (GUI) of an HMI is what defines the elements that users see on the display screen of a machine's HMI hardware — including mobile devices.

In this guide section, we focus on HMI software primarily related to the user interface and user experience (UX or UE). For more information about related HMI software programming that supports advanced interconnectivity with machine controls as well as enterprise-level operations and IIoT functionalities, refer to the section titled HMI networking and connectivity in 2021.

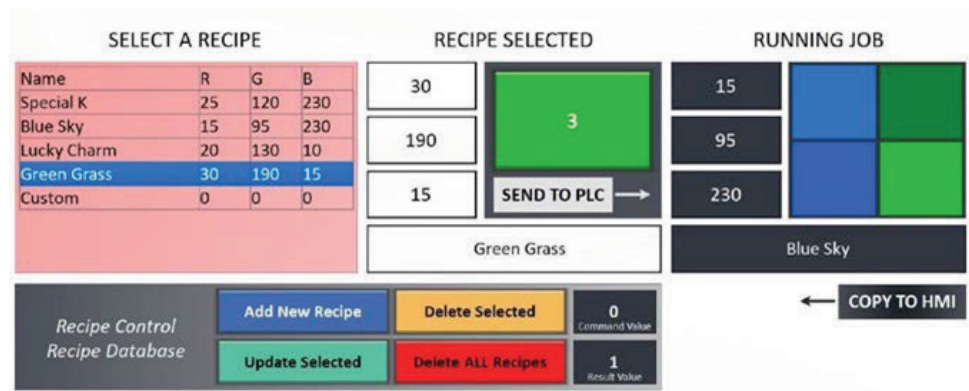
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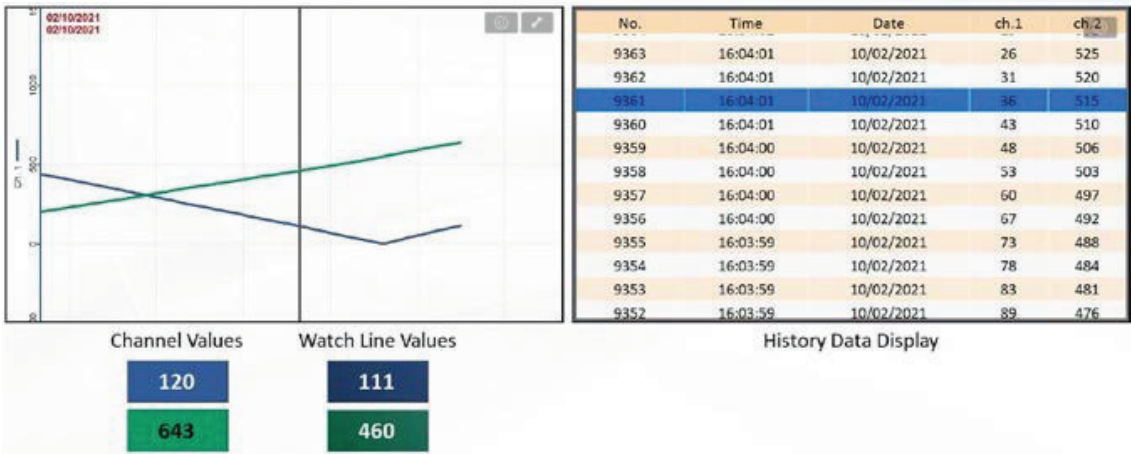
# HMI configuration software (continued)

Software related to the graphical user interface (GUI) of an HMI is what defines the elements that users see on the display screens of a machine’s HMI hardware. All HMIs (no matter how simple or sophisticated) include software defining a GUI that’s tailored to the machine operator. Final HMI programming is usually through Windows-based software or equivalent screen-editor software. That lets designers quickly edit schematics and set the right communication protocols in a familiar programming environment. [Read more about our HMI configuration software.](#)

Poor HMI designs degrade machine operators’ psychosocial state and increase the risk of accidents. Overly complicated, ambiguous, and disorganized HMI screens can confuse machine operators while overly simplified HMI screens may disallow operator interest in optimizing or tracking automated processes. More sophisticated systems regularly allow higher-level access to managers and similar individuals at the organization. But HMI GUIs that best serve the machine operator include pertinent diagrams, digital photos, and detailed systems schematics as needed — and leverage the full power of the control system’s architecture to deliver top performance requirements even while staying within HMI procurement-budget restrictions.



*A recipe in the context of HMIs is a collection of all parameters associated with the production of a given end product. Via HMIs, these recipes can be updated and loaded on demand. Visit our [Video Center](#) to watch helpful videos on the features and how to get started using our configuration software.*



Maple Systems HMIs can perform data logging, historian, and trend-tracking functions. Click [here](#) to see a list and description of features in our HMI configuration software, EBPro.

## CUSTOMIZING AND INTEGRATING AN HMI WITH SOFTWARE

Well-designed HMIs serve very specific predefined functions with screens deliberately tailored to specific personnel interactions with the attached machine. A consistent look and feel (ideally to match the feel of the machine builder's end product, if the HMI is purchased via an integrator or value-adding OEM) is also helpful in minimizing distractions and boosting end-user comfort with the interface.

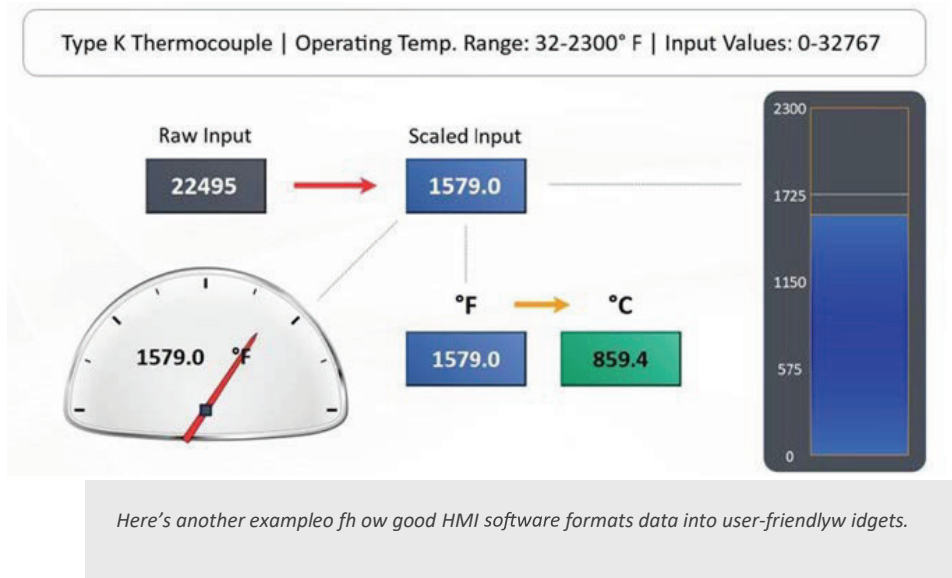
In fact, the U.S. Dept. of Labor's Occupational Safety and Health Administration (OSHA) and the European Agency for Safety and Health at Work outline how HMIs (and any peripheral keyboards, switches, and levers as covered in this guide's previous section) should be installed to ensure their physically safe use by workers. In recent years, the GUIs of HMI displays have also seen improvements as their psychological ergonomics have been studied and best practices defined.

GUI design is important work, as HMIs can have huge impact on the safety and health of machine operators who in many cases spend their whole shift in the HMI's vicinity. That's especially true considering how many such workers have little control over their work environment or hours — and must often perform their duties in noisy settings that may also be fume, dusty, cold, hot, dangerous, or otherwise stressful — including those in manufacturing, automated warehousing, construction, packaging, and automated agriculture.

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## HMI configuration software (continued)



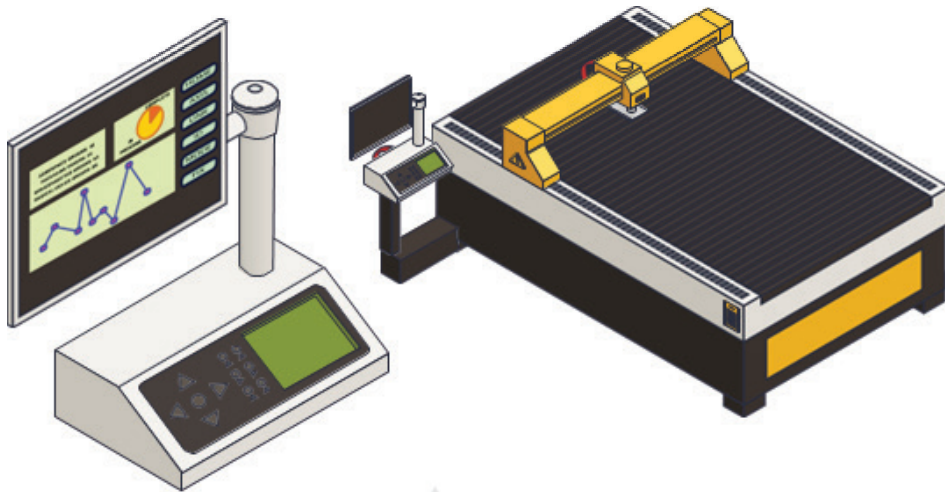
Brute-force HMI-software design approaches such as using a machine's control diagram as the basis of an HMI's navigational structure or jamming all machine data into the HM interface are best avoided. That's because HMI screen layouts yielded by such approaches force personnel to flip around to various screens to prompt the machine to execute a single task. Better HMI software consolidates items into screens dedicated to single machine actions ... and accommodates how people can concurrently handle just a few pieces of data. That means ideally HMI screens only require that operators check a few things before taking appropriate action .

One of several options is to organize the HMI's navigational structure into a hierarchy. Then a top-level homescreen provides the "big picture" of machine status and items potentially needing attention. For example, a homescreen might aggregate all system alarms in the form of badges on its various navigation icons — just as consumer cellphones display notification badges on app icons to draw user attention. Then the HMI user can simply touch the badges (coded from most to least critical) to directly navigate to the screens allowing handling of those alarms.



One level down from the top-level homescreen are a set of operation screens ideally stripped of all but immediately helpful information allow access to setting adjustments. It is at this level that HMI tasks related to observing processes and simple variable and setpoint changes occur. For example, the machine-startup process might have its own dedicated HMI operation screen showing a streamlined safety checklist and action items for proper initiation. That helps errorproof even fairly complicated startup procedures. One level deeper — and ideally accessible from relevant operation screens — are screens that detail machine functions at the control level. Shown here might be diagrams and items that support the actions prompted by operation-screen options.

The final layer of screens in hierarchically organized HMI software contains analysis and help content with items related to control tuning, throughput trends, and alarm and event analyses. This might allow skilled users to reprogram advanced control functions via servomotor parameter adjustments and global commands involving multiple axes.



*Increased automation demands a holistic approach that accommodates how human personnel physically and mentally interact with machine HMIs. Otherwise, operations can face degraded throughput, stressed workers, and unplanned downtime due to accidents.*

## HMI configuration software (continued)

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Here's a more detailed listing of potential HMI design problems and potential solutions.

### 1. Survey plant personnel and then train them on the final HMI design

Designers who are only partially familiar with the processes to be monitored and controlled via HMIs often build systems that necessitate long user instructions and lots of training — with screens and menus that overload operators with uninterpretable data. Better HMI software is possible when engineers consult with machine operators and plant personnel during the design — as these individuals are often most familiar with the processes to be monitored and controlled via HMIs. Deployment of (and collection of user feedback on) prototype HMIs is essential here. In fact, through the use of HMI design mockups, plant workers can often inform engineers about which communication and function improvements would be most useful. They can also lend insight into the real-world perceptual processes that occur when users interact with HMIs — including:

- ☒ Sensory stimulation — how an HMI user initially receives onscreen information
- ☒ Mental organization — how a typical HMI user recognizes HMI elements based on past experiences
- ☒ Interpretation-evaluation — how an HMI user judges the machine status communicated by the HMI — and what response actions might be appropriate
- ☒ Recall—including how easily the HMI's screen hierarchy is committed to regular users' memories

### 2. Streamline HMI screens

Accidents on the plant floor or involving remotely located equipment can often trace their roots to overcomplicated HMI screens. The solution is operation screens with the fewest possible number of elements to allow the machine tasks at hand ... even if that means a cleaner look and avoiding hyper-realistic renderings of machine subsystems.

### 3. Program the HMI to graphically present data wherever possible

Nothing is worse than being asked to make a quick decision based on data contained in a spreadsheet. Good HMI software consolidates all such tabular information into virtual-dashboard graphs and charts. In addition, well-designed HMIs for more sophisticated machines leverage the power of IIoT technologies by directly collecting (and presenting in graphical form) information from sensors and smart meters at key locations on the machine.

Such peripheral components let HMIs give users current machine values relative to setpoints and recommended limits as well as trendlines to inform immediately pressing and preemptive operator actions. That allows something called situational awareness — machine-supported recognition by machine operators of situations that are both typical and atypical for the automated design.

### 4. Provide dedicated maintenance screens and menus

Besides causing trouble during normal plant or equipment operation, poorly designed HMI screens can also fail maintenance personnel during nonroutine troubleshooting and repair procedures. The solution is to give maintenance personnel their own operation screen accessible from the navigational structure's top-level homescreen. This screen can allow safe-mode operation along with the braking of dangerous axes and non-loaded performance drills.

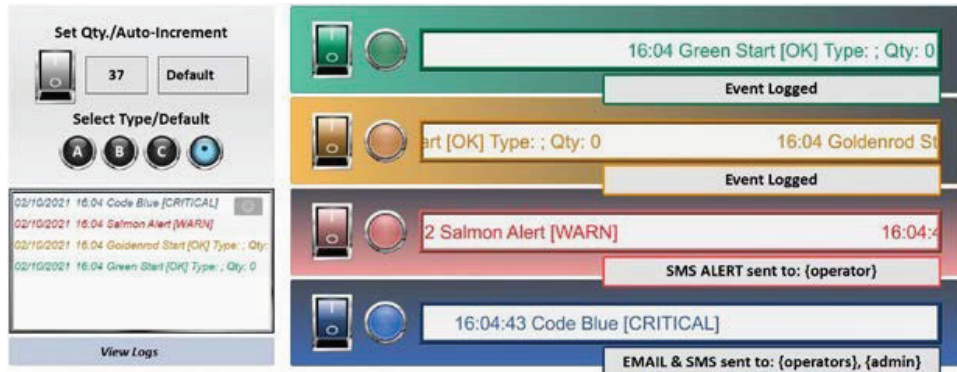


*HMIs that allow safe modest hrough a dedicated operation screen can both improve the efficiency and safety of maintenance work ona utomated systems*

## HMI configuration software (continued)

### 5. Use consistent HMI symbology

Software with a mismatched hodgepodge of button, screen, and icon styles is distracting. In contrast, HMI software that establishes (and consistently applies) a defined layout and set of symbols, icons, and colorized badges is easier to understand and often speeds upfront setup as well. Most major HMI suppliers include in their configuration tools both templates and preset symbol libraries — with the former dictating (among other things) the use of fonts and colors and the latter sometimes grouped by industry or application. In fact, the use of color on HMI screens (due to its unparalleled ability to focus operator attention and communicate meaning) should be strategic. Of course, no dangerous condition should be solely communicated via an HMI with element colorization ... but yellows and reds (when judiciously and consistently applied) can complement other onscreen warning and alert elements.



*Color-coded events and alarms can help make HMI screens more intuitive to use. Build safe, easy to read interface screens using the Easy Builder Pro software for Maple Systems HMI.*

## 6. Use HMI alarms sparingly and ensure they're meaningful

Annoying, ambiguous, tortuously loud, or histrionically persistent HMI alarms can prompt operators to ignore or silence them all — or make unauthorized (and potentially dangerous) machine modifications to prevent alarms from triggering in the first place. HMI software that allows alarm popups to cover other alarm popups is also problematic — especially where critical items needing immediate attention are obscured. In contrast, good HMI designs only generate alarms for situations demanding prompt operator action. They also unburden machine operators from having to mentally prioritize alarms — usually with a color-coded and numbered system that displays a persistent badge (present on all screens) for maximally critical alarms and a ranking system of all other alarms — based on how long the alarm can be safely sidelined until action is taken. Where appropriate, HMIs with internet connectivity can even offload maintenance or management-related alarms to the appropriate staff in the form of emails.

## 7. Recognize how HMIs connect increasingly complex systems — and plan accordingly

As we'll cover in subsequent sections of this guide, HMIs are often at the heart of highly advanced IIoT installations — especially for pharmaceutical and medical-device manufacture. Their primary function as feedback and control hubs supports their role in leading-edge operations that allow continuous real-time optimization. The challenge is that leveraging the full potential of HMI connectivity is dependent on good design of software with which design engineers may have rarely or never worked. Educational tools, HMI configuration modules, and component-s upplier support can help address this challenge.



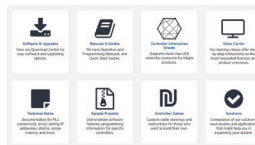
### [Quick Start Guide](#)

Our Quick Start Guide brings you up to speed quickly. We recommend using this guide in conjunction with the Quick Start project files, this step-by-step guide walks you through creating your first project.



### [Sample Projects](#)

We have created sample applications/ projects and sample kits that demonstrate software features, give programming information for specific controllers, or demonstrate product capabilities.



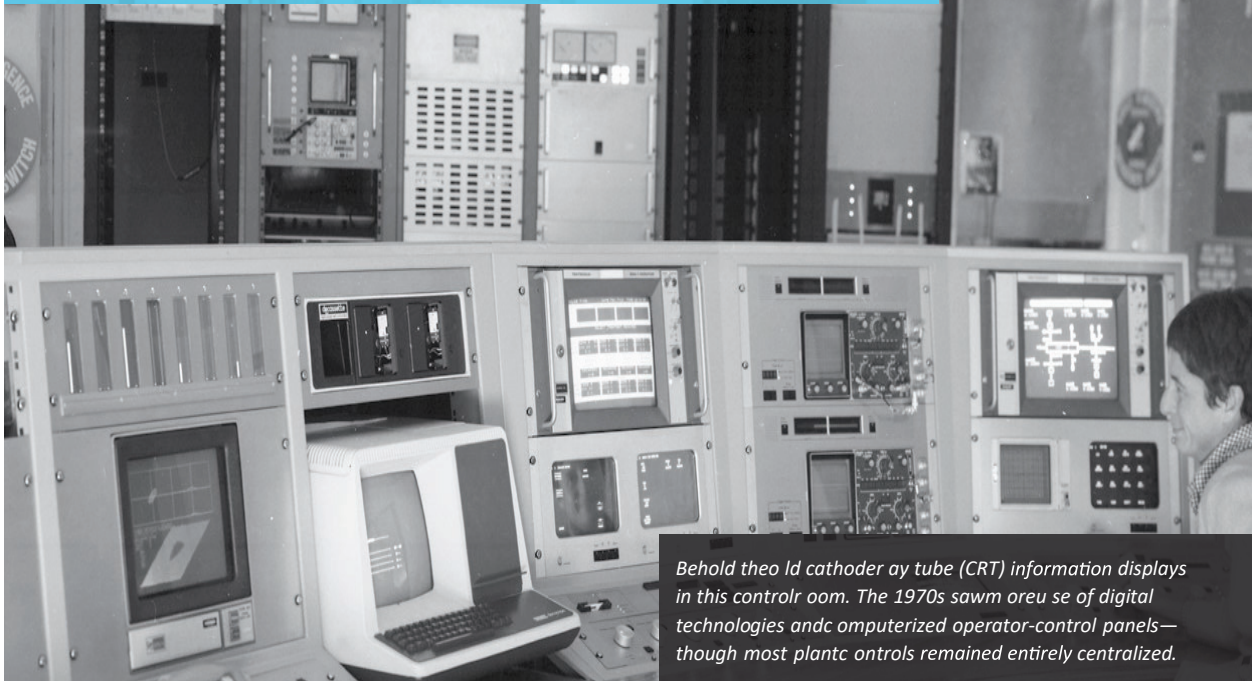
### [Additional Resources](#)

Download software, manuals, guides sample projects, controller information sheets, cable drawings, CAD drawings, tech notes, or watch a tutorial video to get you started in our Support Center.



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# HMIs integrating control functions —then and now



*Behold the old cathode ray tube (CRT) information displays in this control room. The 1970s saw the use of digital technologies and computerized operator-control panels—though most plant controls remained entirely centralized.*

Pre-integration of related components by suppliers is a trend seen across the automation industry—in housings that integrate their own bearings and seals, cable carriers that integrate their own connectorized cables, motors that integrate their own drives, belt pulleys that integrate their own locking devices, conveyors that integrate their own sensors, and actuators and stages that integrate... well, everything related to imparting motion to an axis. No doubt industry can expect to see suppliers assuming even more of component and system integration in coming years—especially as design engineers are encouraged to focus on core competencies even if that requires the outsourcing of the motion system design.

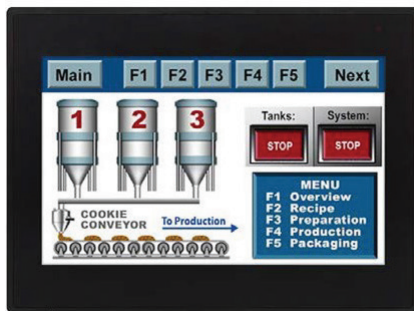


HMI's are no exception to this integration trend ... and industry has seen many new offerings on the market that can handle the traditional HMI functions of data collection as well as batch processing and of course displaying information ... as well as various control functions. We offer HMI + PLC options that do just that, HMI functions and PLC control.

The benefits of such integration include:

- ☒ Fewer parts and less cabling
- ☒ A compact design that takes up less space on a machine
- ☒ Centralized control and interface
- ☒ Shorter development time thanks in part to a single development environment

Utilized worldwide to employ diverse applications, our HMI PLCs lower costs, save space, and feature options including: Serial and Ethernet communication, support for Class I, Division 2 installations, and numerous I/O configurations.



These model [HMC3070A-M HMI-PLC](#) combination unit from Maple Systems features a 7-in. screen with built-in I/O including a USB and Ethernet port, two serial ports, and is expandable to include up to three I/O modules.



HMI-PLC combination units such as the [HMC3070A-M](#) from Maple Systems can be programmed with either native ladder logic or IEC 61131-3 logic languages. Many HMI-PLC combination units also offer high-speed counters and PWM I/O modules.

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## HMIs integrating control functions—then and now (continued)

**First a history lesson to put this in perspective:** Early precursors to modern HMIs for automation were based on cathode ray tube (CRT) information displays complemented by other programming-terminal peripheral devices such as keyboards. The latter were especially important in applications needing frequent program changes or text inputs —s uch as machining based on CNC, for example. Basically, CRTs use high-voltage power supplies to generate and steer electron beams at phosphor dots on glass tubes' interiors.

Of course, such CRT technology required bulky and expensive transformers and coils ... and generated magnetic fields. That's why early-generation programming terminals for initial or occasional writing of control-system software (as well as downloading and debugging user code) would wherever possible employ temporary connections to display screens. These let programmers see what they were doing but avoided the drawbacks of permanent CRT connections. In fact, yet another approach that was (and in some cases remains) common for relay-based control systems was to simply rely on traditional tactile-control user-input components such as pushbuttons described earlier in this guide and status outputs such as pilot lights for a low-cost machine I/O arrangement.

**Fast forward to today:** Since the advent of low-cost flatscreen displays, the cost of packaging modern HMIs into control systems has plummeted. A concurrent drop in prices for other control-panel technologies means that today, even OITs come with modest one or two-line displays that are digitally programmable. But touchscreen functionalities complemented with the ability to display text, images, and even videos have made HMIs the most powerful and cost effective operator interface for a lot of machinery.

*Shown here is an od-  
ern HMI example  
from the machine-  
tool industry.*



## INDUSTRIAL PCs WITH HMI FUNCTIONALITY

A common HMI variation now taken for granted are those built around Industrial PCs. In fact, it's astounding how most design engineers today would likely define HMIs to be self-contained PCs or equivalent fanless electronics based on a single circuit board running Linux or other operating system (OS). Such Industrial PC components are more complicated and costlier than some alternatives due to their inclusion of more electronics and software resources. Nevertheless, they've become standard components over the last 20 or so years — executing (in traditional setups) the Industrial PC based machine controls on a common microprocessor. The last few years have even seen new Industrial PC iterations with dual and even quad-core processors (1 and 1.6-GHz) for the benefits of an integrated system but segregation of HMI and control functions for real-time handling of advanced motion and automation tasks.

No matter the exact PC electronics, HMIs built into PC-based systems are part of a multi-function design. In many cases, that makes it possible to expand system functions as needed. Later in this guide we will detail how some such HMI systems often deliver capabilities beyond machine control — including digital and analog I/O-based integration into automated factory and enterprise-level systems.

The assumption of control functions is a natural progression of HMI technology, as traditional PCs are all based on a centralized processor hosting an OS that manages attached resources — including memory, external communications, and (most significantly to this topic) visual display. That means employing a PC already in the system to manage an industrial screen incurs no additional cost. When suppliers manufacture the PC components to fit into a flat format, this imparts yet another benefit ... namely, a streamlined and economical amalgam component with a single housing and mount.

Industrial PC products also facilitate efficient fault and diagnostic messaging, adjustments of machine functions for maintenance and repair tasks, and network communications. No wonder Industrial PC products that combine a touchscreen with control electronics have become so common in automated applications.

Note there is one important caveat to using Industrial PC capable of controls: Design engineers accustomed to traditional design approaches might be inclined to specify a control system and then a more or less suitable HMI later in the design process. Specifying Industrial PC components or really any format of HMI that assumes control functions necessitates a more holistic design approach to leverage all components' interoperability.

## HMIs integrating control functions—then and now (continued)

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### OTHER HMI+CONTROL COMBINATIONS AND WHERE THEY MAKE SENSE

Some HMIs today take the form of low-maintenance cost-effective embedded HMIs — run on an embedded OS to consume minimal memory and processing power. That’s because the software of embedded HMIs are specifically optimized for HMI computational processes and nothing more. In contrast with the Industrial PCs covered earlier which require engineers to purchase and install software on their own. Most such embedded HMIs are prepackaged and preinstalled with OS and application software. Make no mistake, though: Embedded HMIs are often quite sophisticated ... especially when installed in networked arrays.

Some Maple Systems HMIs can even execute tasks typically associated with PLCs. These are sometimes billed as including soft PLC functions — utilities that have long been machine-control industry standard. Read more about our [HMIs that support CODESYS](#) (CODESYS provides a control solution that is one of the most complete implementations of the IEC 61131-3 standard for PLC software on the market).

Recall that standalone PLC formats range from the simplest of controllers (capable of executing only basic ladder-logic instruction sets) to sophisticated multi-function components commanding multiple control modes — over processes and even motion-control applications in some cases. The range of HMI PLC capabilities is equally diverse.

That said, most HMIs powerful enough to assume PLC functions (thanks to processing and memory sufficient for running software as well as Ethernet, I/O, COM, or other connectivity) can execute the HMI tasks of data logging, plotting, and graphing along with alarm setting and trend monitoring — as well as PLC tasks including:

- ☒ I/O data processing and handling
- ☒ Execution of all PLC ladder-logic instructions and PID control over discrete motion tasks
- ☒ Execution any other programming written in a licensed copy of IEC 61131-3 Controller Development System (CODESYS)
- ☒ Deterministic and real-time control over critical operations

## APPLICATION EXAMPLE: HMIs ON MEDICAL-DEVICE MANUFACTURING EQUIPMENT

Most hospitalized patients receive an IV soon after admission ... and sometimes insertion of the needle is painful. But once placed, discomfort subsides — as the plastic tubing that connects the IV bag to the arm is shaped to smoothly glide into veins and remain comfortable during use. Equipment made by Silverstone Automation — the manufacturer’s SilverCATH 1100 and 2200 series machines — forms plastic tubing that functions as these catheter tips.

When Silverstone designed the SilverCATH machines, they needed a display to deliver a high-resolution touchscreen with built-in recipe functionality; a USB port for saving recipe data; user-friendly programming; and password-protected screens. So Silverstone ultimately integrated Maple Systems HMI5100L human-machine interfaces (HMIs) into their machines. The HMI5100L is slim and affordable. Its 1.57-in. depth simplifies mounting, and its easy-to-read 10-in. color touchscreen lets operators quickly set parameters.

The touchscreens (which display separate screens for operators and technicians) simplify controls and prevent unintended entries. Plus preprogrammed recipes freed operators from entering lots of data before each changeover.

In fact, Silverstone also includes Maple Systems HMIs into an array of proprietary machine designs. Maple Systems tailors the controllers to Silverstone requirements with offerings from 4.3 to 15 in.



*Silverstone Automation makes an array of medical- device manufacturing equipment. The machine builder’s SilverCATH 1100 and 2200 machines accurately form introducer and catheter tips. These incorporate Maple Systems HMIs for cost-effective and user-friendly operation.*

## CONCLUDING THOUGHTS ON HMI-BASED CONTROLS

Recent years have brought staggering advancements in HMI control functionalities — and (as we’ll explore in this Design Guide’s next section) IIoT functionalities as well. So while previously only modest applications could rely solely on HMIs with soft-PLC or PC functions for controls, today’s HMI technologies can often satisfy the same requirements for even more demanding installations.

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# HMI networking and connectivity



*Some HMIs can directly connect with remote I/O components. That simplifies integration for what's called edge computing in automation.*

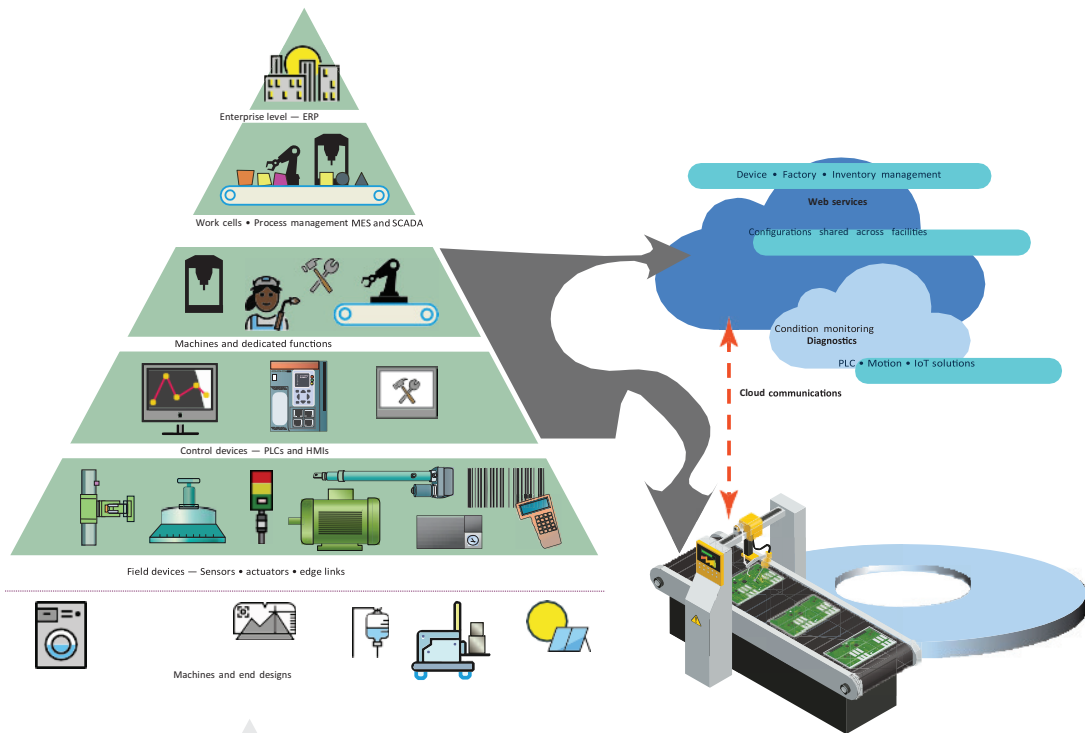
Earlier in this guide, we explained the software that lets developers optimize the visual user interface and user experience (UX or UE) of HMIs. Now it's time to consider the software and complementary hardware that supports interconnectivity with machine controls and business-level systems.

These take the form of:

- ☒ Communications between machine-level and supervisory HMI systems ... as billed by some manufacturers, the intersection of machine automation and factory automation
- ☒ Enterprise-level operations and IIoT functionalities leveraging cloud connectivity

Here it's helpful to reference the hierarchal system architecture that's traditionally described automated operations — even if edge and cloud computing and other IIoT functionalities have significantly blurred the lines separating system functions.





*Traditional factory automation has a hierarchal system architecture. But cloud and fog computing (data processing on the shop floor) are on the rise, and that's blurred the lines demarcating component functions. Edge-level solutions with high computing power have accelerated this trend.*

## HMI network and connectivity (continued)

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In the following descriptions, we describe the system functions as they operate in plants involving discrete automation (and not process automation).

The hierarchal structure so ingrained in engineering's understanding of operations leveraging automation for industrial applications puts at it pyramid pinnacle all enterprise- level structures. These include business-management systems that track and command actions on budgets and invoices, raw material stock, out-standing purchasing order statuses, personnel scheduling, production volumes, quality-control statistics, and shipments pending and out.

Such track and command functions are executed by enterprise resource planning (ERP) systems mentioned earlier in this guide as well as advanced planning systems (APSs) and manufacturing resource planning (MRP) systems.

Software supporting such enterprise-level systems (among other things) log and monitor the status of customer orders, trigger the procurement of input materials when needed, and sometimes group orders into batches for efficient production schedules. Traditionally, it was only upon the close of business each day (or order-lot completions) that ERP-logged production information and statistics got used.

## HOW HMIs RELATE TO MANUFACTURING EXECUTION SYSTEMS (MESs) AND SCADA SYSTEMS

Underpinning ERP and other enterprise-level systems are manufacturing execution systems (MESs) to track and control in near real-time the more specific processes by which manufacturing subcomponents or equivalent supplies are dispensed, sorted, divided, assembled, treated, packaged, and otherwise finished into discrete items. Most MESs are capable of second-by-second tracking of operations to immediately report to plant managers current inventory, product-genealogy records, scheduling items, and operational information.



## HMI network and connectivity (continued)

MESs can also trigger actions to prompt or change work in progress; address machine-maintenance or quality -control issues; dispatch production to prioritized tasks; inventory items; distribute instructions and documentation; and perform various analyses. Though overlapping with ERP or MRP execution of some of these items, MES execution is exhaustive to satisfy plant-floor demands for more granular data. That's especially true where MESs inform machine changeovers to have machinery produce a new product.

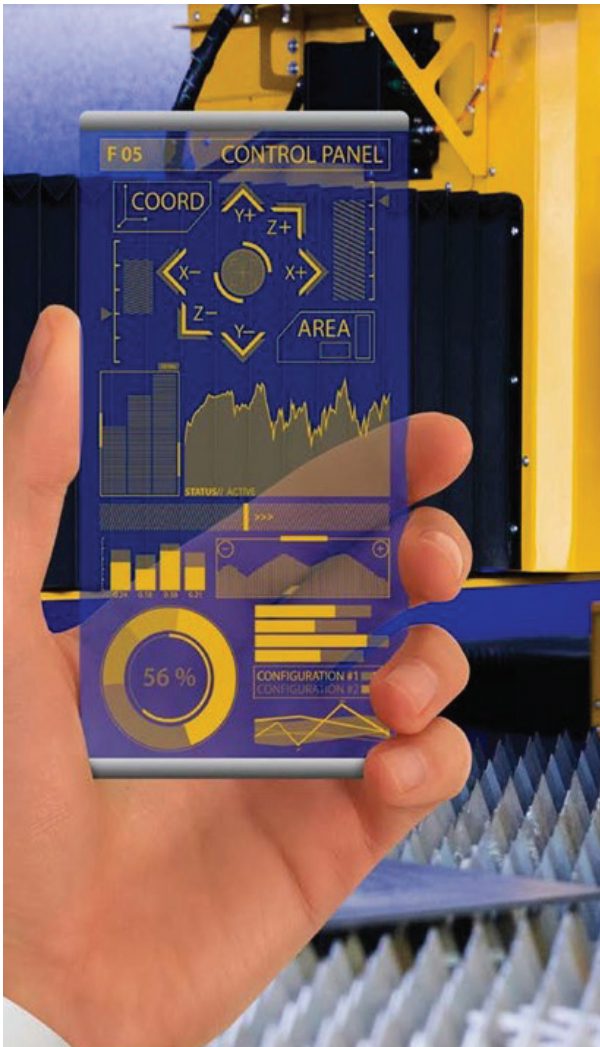
Today Maple Systems HMIs and Industrial PCs impart IIoT functionality to these part-production-tracking MESs as well as supervisory control and data acquisition (SCADA) systems that actually control production in real-time. That's especially true where automated operations aim to:

- ☒ **Reduce or remove reliance upon non- integrated communications and personnel expertise in daily operations**
- ☒ **Consolidate otherwise disparate software and controls**
- ☒ **Make more use of plant and machine data in increasingly automated or remote operations**

HMI involvement in global facility operations is where there's intersection with SCADA functions — especially local or remote- HMI machine control, HMI-based upper-level monitoring, and real-time HMI data collection and logging. In effect, these HMI functions turn the machines to which they connect into IIoT data sources.



*Maple Systems HMI IIoT connectivity options abound.*



*HMI capabilities with IIoT functions include real-time supervision as well as advanced event logging and triggering, diagnostics, and additional enterprise-level monitoring.*

## HMIS, GATEWAYS, AND CONNECTIVITY FOR MACHINE AND FACTORY-LEVEL AUTOMATION

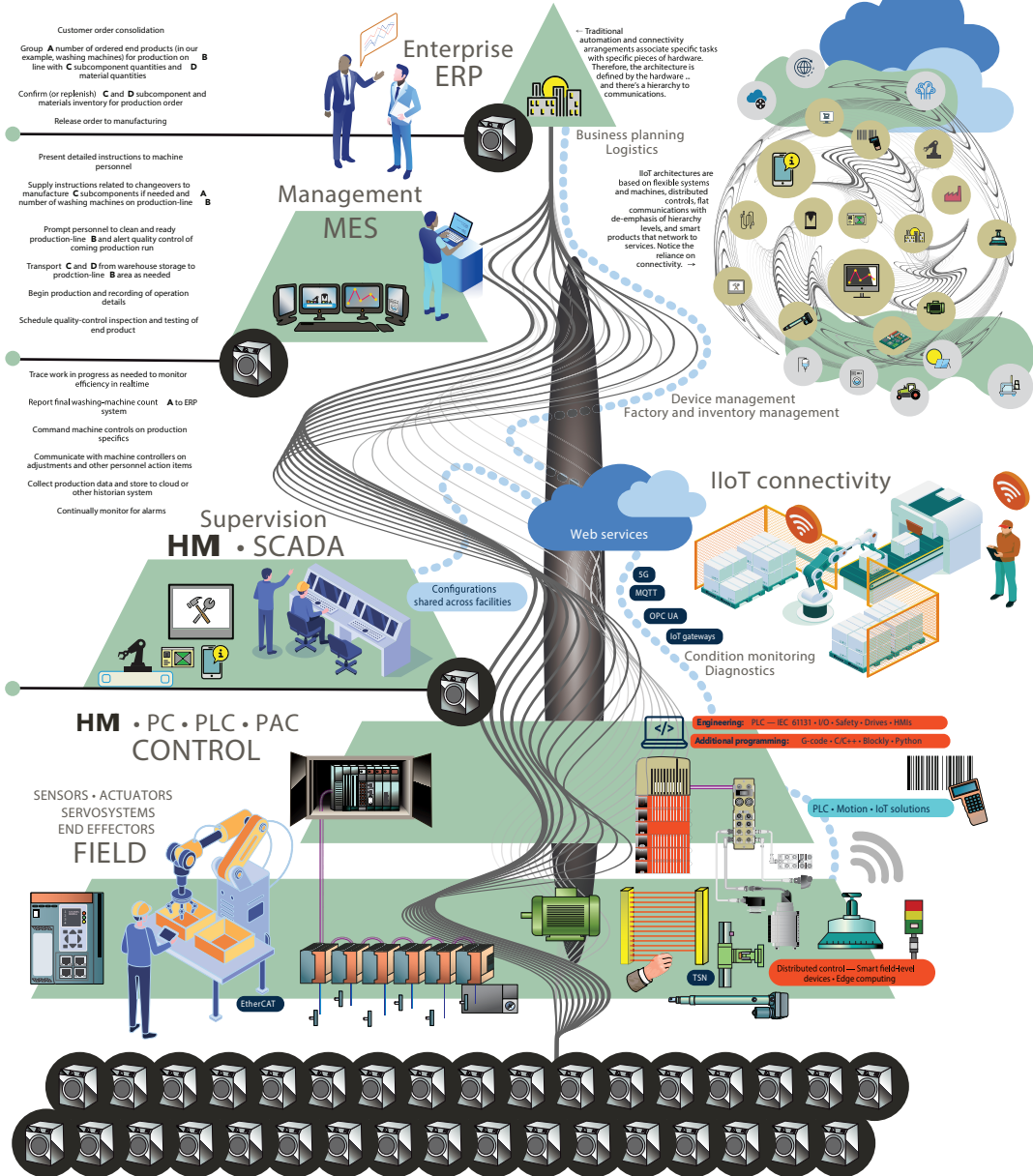
Maple System's HMIs support increased IIoT interoperability of manufacturing execution systems with other operational systems through:

- ☒ Supplier-agnostic and open-standard hardware connectivity — including copious use of Ethernet-based connectivity.
- ☒ Our HMIs support Cloud-based web services/ Component-supplier development and operating software ecosystems like Microsoft Azure, AWS, Google Cloud, and more.
- ☒ Connections with or integration of gateways — the passthroughs that bridge networks and interpret differing languages.
- ☒ IIoT protocols like [MQTT](#), [OPC UA](#), [SQL Database](#), Ignition, Sparkplug B, and more.
- ☒ Support for over 300 PLCs and controllers like Allen-Bradley, Omron, Schneider, Idec, and many, many more. [Read more](#) about what protocols we support here.

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# How HMIs fit into ONE PRODUCTION CYCLE



Industry uses a wide array of terms to group and define the tasks associated with manufacturing management. One term widely used by both discrete as well as process (batch) automation organizations is manufacturing execution systems or MESs. This refers to the intermediate automation systems with which HMIs are primarily associated. Other partially equivalent terms include manufacturing operations management or MOM (more heavily oriented to discrete control) and production process management or PPM.



## HMI network and connectivity (continued)



*Maple Systems' dual-ethernet HMIs divide industrial control and remote access functionality between separate Ethernet networks—a n internal industrial communications network and an external wide area network (WAN). This offers IIoT functionality plus security. 10/100/1000 Base-T dual Ethernet ports and a 1-GHz processor maximize performance.*

New installations — especially for packaging and printing OEMs — benefit from how IIoT edge devices and gateways can adapt to most all devices and enterprise systems in the marketplace—and in some cases, to multiple PLCs at a time. That lets automated facilities leverage more accessible production information for real-time process optimization ... and to develop useful features for future machine iterations. But gateways are also vital for retrofitting IIoT functions into older brownfield equipment needing upgrades, as gateways (with software) provide single-point data collection and preprocessing before sending data onwards to the MES. Such legacy systems primarily benefit increased gateway-facilitated connectivity for smarter use of feedback, edge computing, and unification of disparate systems.

No wonder HMIs having integrated gateway functions are increasingly common —Advanced connectivity from such HMIs can facilitate the complex motion required for myriad discrete-automation tasks — and allow enterprise and cloud connectivity.

**Factory automation HMI gateway tasks:** Gateway HMIs facilitate communications for MES and SCADA operations we've already covered, including consumable- materials management, contextualized visualizations, and cellular connectivity to remote machines. As mentioned, many allow remote access to connected PLCs ... whether standalone PLCs from various manufacturers or built-in soft PLCs. Those accepting setup via one common software (supporting multiple programming languages and communication drivers) deliver the tightest-integrated IoT operations.

**Machine automation HMI gateway tasks:** Some HMIs with sub-elements for serving as gateways can also run across control and data-transfer functions ... and some even support edge computing also called fog computing. Distributed intelligence and data processing out at a design's most distal device levels (before data heads onward) have been available for some time. However, devices with more computing power than in the past now allow:

- ☒ More data preprocessing of facilitate control, HMI, SCADA, and MES use of that data
- ☒ The leveraging of wirelessly connected smart field devices for predictive-maintenance functions
- ☒ Multiple modes of system monitoring
- ☒ Data backup when cloud links are temporarily unavailable
- ☒ Better end-effector performance

Edge-computing offerings for the latter are by definition very applications-specific— such as pneumatically and motor-driven tools with feedback for precise fastening in assembly operations (to give one example). Or an adaptive -resistance weld controller might manage weld growth in real-time with onboard logic for repeatable spot quality ... even on varied combinations of sheet thicknesses and materials. Gateway HMIs on such machinery essentially assist in directing and prioritizing commands originating from edge and central machine controls.

*Designed to add new communications protocols to existing systems, our Serial and Bridge Gateway products will get your legacy systems talking to your management network in a low cost, low effort way. Unlike other gateway products with limited connectivity, our Gateway models offer a vast selection of communications drivers and controllers and then transmit that data to SCADA and ERP systems using the most popular IIoT protocol to get your existing systems.*

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## HMI network and connectivity (continued)

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Note the slight distinction between edge device and gateway functions. In hierarchal models of automated industrial operations, devices include motors, drives, linear actuators, and various feedback devices such as encoders and standalone sensors ... and are at the bottom of the pyramid. Traditional machines use no “smart devices” or intelligence at their outermost reaches. In contrast, smart edge devices incorporate sensors or electronics to let end users get and evaluate distilled data from the automated design. In other words, devices involved in edge computing employ logic resources to process data before sending it onward to controls, the cloud, onsite servers, or other IT infrastructures.

Note how that’s different from some IoT gateways that may only send data from a machine onward — without processing that data.

In recent years, many suppliers (especially motion-component suppliers) have imparted their offerings with more logic and analytics capabilities for decentralized control, design scalability, and modular machines. Gateway HMIs and controls complete systems based on such components ... often allowing entirely new modes of automation to emerge.

**Case in point:** HMIs and smart devices can make automated facilities entirely reconfigurable. Consider a factory housing a handful of movable plug-and-run machines that are interoperable so (when joined together) automatically identify parallel equipment, upstream connections, and software residents.

Coding (ideally based on open standards) with precanned kinematics and function libraries complements the machines’ adaptability. Such machine designs might work in a facility packaging both powder and liquid consumer detergents: Here, separate machines for infeed, pick and place, packaging, palletizing, and outfeed functions can quickly break apart and reconnect for efficient product changeovers — which is especially useful for satisfying small batch sizes.

Reprogramming is unnecessary. Instead, an engineer simply enters a few configuration values into a master HMI. Then the HMI directs that engineer on how to put the right machine modules together for the next production run. Configuration values in this context primarily dictate adjustment actions and their sequence — for example, relating to the height of conveyor-belt transfer points; positions to which workpieces must be delivered; and the speed at which pieces can be processed. Once all the machines’ physical interfaces are set, production starts.



*Maple Systems HMIs can physically accommodate and virtually unify all components in a host communication environment.*

#### **HMIs (AND ETHERNET) AS THE HUB FOR VARIOUS COMMUNICATIONS**

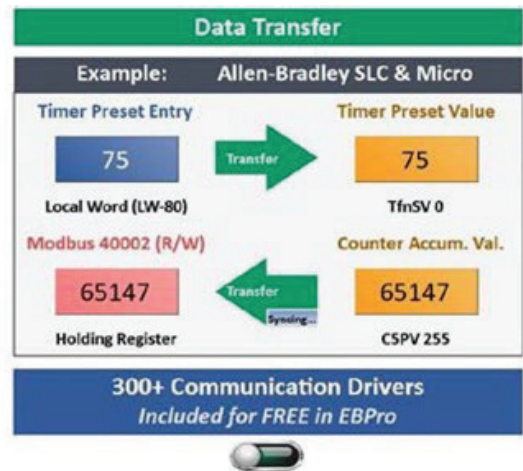
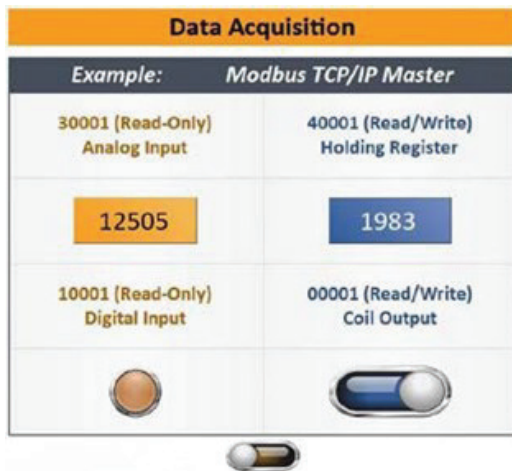
HMIs are a flexible, expandable, and sensical place to accept and unify disparate automation-system communications. After all, they are in most systems already connected to numerous devices and controls. A lot of times unification means HMIs accommodate field components physically connected by serial as well as Ethernet links.

To illustrate, an HMI might include gateway functions to join linear actuators and other devices to an installation's CC-Link network ... and for outbound control convert data from a host CC-Link communications protocol to devices' RS-232 or RS-485 protocols, for example. Or consider another variation: Depending on the HMI setup, multi-network communications might go through ControlNet and DeviceNet. ControlNet is a control-level network for high-speed transmission of time-critical messaging data and I/O data. In contrast, DeviceNet handles industrial devices such as drives, limit switches, motor starters, operator displays, photoelectric cells, and valve manifolds — as well as PCs and PLCs that may connect to the machine. HMIs that use both communications boost machine-data accessibility.

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## HMI network and connectivity (continued)



*A Modbus gateway function in our HMIs can pass information from the plant floor to remote SCADA systems by translating data from several PLC protocols out of hundreds from various manufacturers via a default Modbus TCP/IP industrial standard protocol.*

The usefulness of HMI-based communication unification is particularly useful in systems incorporating a lot of Ethernet — and its support of simultaneous communication of multiple protocols on a given network. No wonder there's been unfettered industrial adoption of Ethernet for the physical connections of data and control communications continues unabated. Currently leading is 802.3 (1 Gbit/sec or GbE) Ethernet — especially with CAT5e as well as CAT6 Ethernet cables for power over Ethernet (PoE). HMIs are part of this trend, as Ethernet ports are increasingly common on even the simplest HMIs.

Many HMIs can use a single Ethernet network to communicate with to unify several Ethernet-connected PLCs, even if some employ the Modbus TCP/IP protocol and others EtherNet/IP and others Profinet. For example, a Modbus gateway function in some controller HMIs might pass information from the plant floor to remote SCADA systems by translating data from several PLC protocols out of hundreds from various manufacturers via a default Modbus TCP/IP industrial standard protocol.

Compounding the benefits of HMI-Ethernet unification is how five protocols (EtherCAT, CC-Link, EtherNet/IP, PROFINET, and SERCOS III) capitalize on Ethernet to support realtime and deterministic networking — important to the burgeoning area of advanced automation.

## HOW VARIOUS MICROSOFT PRODUCTS SUPPORT SOPHISTICATED HMI FUNCTIONS

It's interesting to note how many software products and standards from Microsoft Corp. have come to advance HMI interoperability and IIoT functions in automation.

Case in point: OPC UA is one networking standard commonly leveraged for HMI interoperability, and traces its roots to the Microsoft Windows OS. Recall that the OPC UA standard from the OPC Foundation was originally named for Object Linking and embedding (of Windows) for Process Control — OPC — unified architecture (UA). Today the OPC stands for Open Platform Communication and countless discrete-manufacturing and automated operations adhere to the OPC UA specifications. Supported by many SCADA, MES, and ERP software providers, any real-time data accessible to the HMI can be organized into multi-level objects with descriptive names. [Read more about how our HMIs support OPC UA.](#)

Elsewhere, Microsoft's Windows 10 IoT Enterprise serves as an OS on some controller HMIs to allow use of open-platform software for transforming and distributing data. That's useful where a controller leverages networking (say, via a CC-Link IE Field industrial network having data exchanges to 1 msec for real-time equipment control) for data computing, remote monitoring, edge computing, and the integration of hardware and software. Our Industrial PCs support Windows 10 IoT. Check out all our [Industrial PCs.](#)



*Ohio-based Kennametal uses Microsoft IoT business and manufacturing products in its operations — including the Azure IoT Hub, Azure cloud platform, Microsoft Dynamics 365, and Microsoft Power BI. The latter turns collected data into actionable business insights. Images courtesy Microsoft Corp. and Kennametal Inc.*

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## HMI network and connectivity (continued)

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As we'll detail later in this guide, many HMI systems can connect with Microsoft Azure IoT Edge — a cloud software and services package — and many of latest motion and automation controllers are certified for Microsoft Azure services. Bringing IoT connectivity full circle here is how compatible devices from controllers outward can employ secure protocols such as MQ telemetry transport (MQTT), advanced message queuing protocol (AMQP), and the aforementioned OPC-UA to make machine data available for analytics, machine learning, and display on HMI dashboards anywhere in the world. Read more about [Maple HMIs, Edge Gateways, and the IIoT](#).

Excel of Microsoft Office is often used to complement IIoT functions on smart HMIs. For example, HMIs that can connect to MySQL and Microsoft SQL Server databases to let plant managers send events, alarms, and logged data to SQL servers and can also manage received data and funnel it directly into corporate data systems via Microsoft Office Excel. Learn more about [SQL databases and Maple Systems HMIs](#).

Microsoft Visual Studio — a program that lets engineers write applications (apps) for Android, iOS, Mac, and Windows devices as well as web and cloud apps — also facilitates a lot of HMI and SCADA software development. More specifically, a number of HMI suppliers offer integrated development software allowing integration with Visual Studio for the writing of adaptable HMI applications. What's more, Visual Studio is particularly well suited for writing programs in HyperText Markup Language 5 (HTML5) for HMI screens that can execute or view on any HMI HTML5-browser-irrespective of device OS specs .

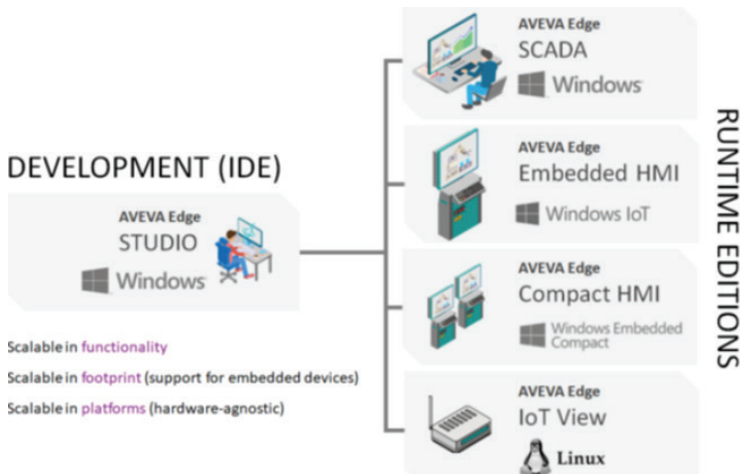
Lastly, [Aveva Edge](#) 2020 development software supports Windows Operating Systems and is used to create the project that resides on the operator interface and operates the target industrial system. Aveva Edge 2020 is completely scalable, meaning that an application built for a Windows mobile device can be scaled up to run on a Windows Server edition, and vice versa. Aveva Edge 2020 embedded is a full featured HMI SCADA software with a small footprint and is available on our website. Learn more [here](#).

A Maple Systems Industrial Panel PC paired with Visual Studio to create a powerful user interface:

Our powerful Industrial Panel PC HMI used as an interface to sophisticated packaging equipment, allowing the OEM to also host the 3rd party PC-based vision software, as well as the data logging, analysis and reporting systems the customer needs.



OMI6808B: 8.0" Panel PC, Intel Pentium® N4200 1.1GHz CPU, Windows® 10 options, Fanless, Rugged Enclosure



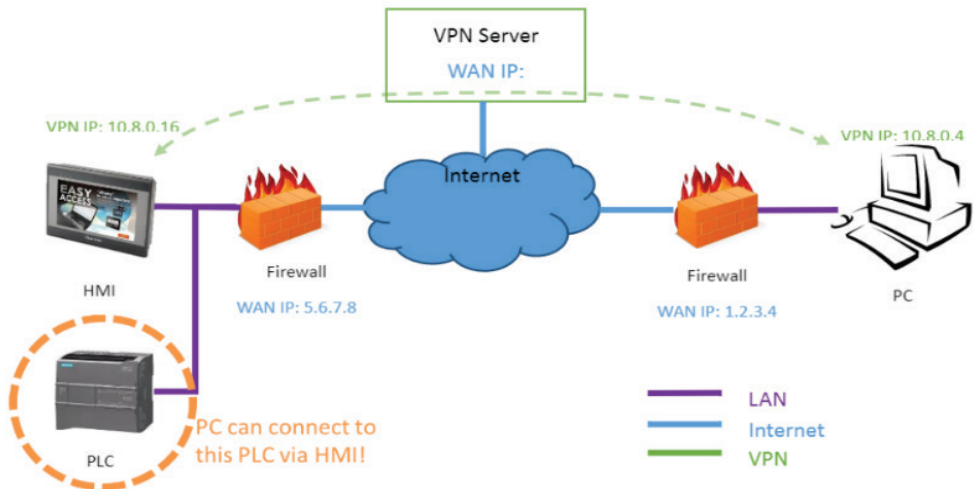
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## HMI network and connectivity (continued)

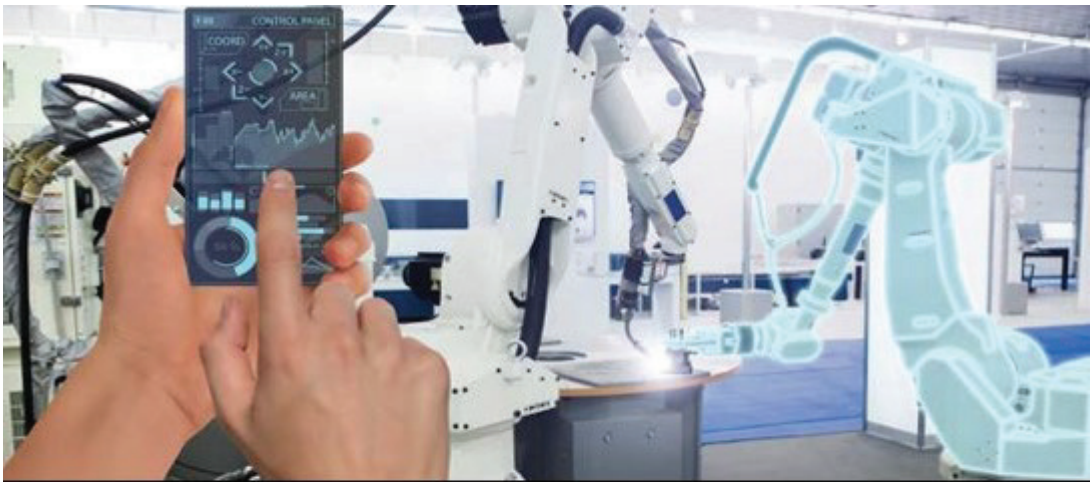
Consider a real-world situation demonstrating the usefulness of remote access interfaces on HMIs. Assume an OEM engineer must troubleshoot a downed machine at an important customer's plant.

Traditionally the engineer may have traveled by air to the plant to fix the machine in person. But now more cost-effective solutions and technology let OEMs leverage remote access from authorized devices (with 256-bit AES- encrypted VPN security) to immediately access and remedy or walk onsite personnel through fixes to troubleshoot and service the downed machine.

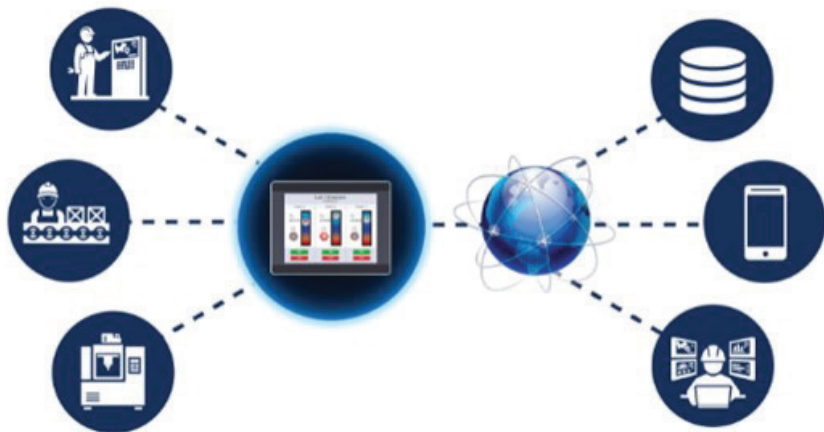


[EasyAccess 2.0](#), a proprietary remote access VPN cloud service available on our headless and touchscreen HMIs, is part of EBPro, our HMI configuration software. [EasyAccess 2.0](#) allows easy remote connection to your HMI via phone, tablet or PC.

The wireless communications, bright displays, and portable processing power of today's mobile devices such as tablets make them appropriate for use as auxiliary and even primary screens in HMI systems.



*Recent years have seen convergence of HMI, connectivity, and controller functions to support highly sophisticated automation and enterprise-level operations.*



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## HMI network and connectivity (continued)

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### BRIEF EXPLANATION OF THE CLOUD SERVICES THAT OUR HMIs ACCESS

Seeing massive adoption for how they support IIoT design approaches are IIoT infrastructure, platform, and software as a service (IaaS, PaaS, and SaaS respectively) or cloud services. These include Alibaba Cloud, Tencent Cloud, Google Cloud, IBM Cloud, and Oracle Cloud. However, in the U.S., today's two leading public (offsite not company or machine network) cloud service providers for machine automation that integrate with Maple HMIs are:

- ☒ Amazon Web Services Inc. with AWS cloud software and services
- ☒ Microsoft with Azure IoT Edge cloud software and services mentioned earlier

Such cloud services primarily support the use of databases (through products such as Amazon simple storage service or S3 buckets and Amazon DynamoDB managed database services), online and local applications, and on-demand computational power. Related to the latter are AWS Lambda services that allow Python, Node.js, Java, and C# programming to run on the service's servers. HMIs let end users make the most of these IIoT functions.

Of course, cloud services serve other functions too. Part of what's driving AWS and Azure adoption for IIoT is how more engineers have become comfortable with building out their own infrastructure on these platforms. After all, cloud-based data services free engineers from extra design work on underlying hardware and software — because the provider executes IT tasks. AWS and Azure also allow use of software that abstracts dataflows and communications — simplifying some design work with development environments having attractive GUIs to shield engineers from dealing with programming minutia.

Cloud services also facilitate advanced engineering with virtual machines that run operating systems and applications ... over which design engineers maintain control. What's more, cloud services can accommodate various communication services on protocols employing publish-subscribe principles — to be the master service for them all. That eliminates the need for time-consuming addressing during system setup.

All such features can facilitate advanced capabilities including machine learning for categorizing and distilling data ... and making predictions to prompt machine and production adjustments.

A related trend is increased use of pre-curated cloud portals from suppliers. These portals (which give engineers a simple way get started with IIoT) are online services that connect with users' controllers and touchscreen HMI's. Then engineers can customize HMI screens and dashboards with trends ... and configure HMI email notifications using a rule engine managed from the cloud portal. The list of functions goes on. Some arrangements allow remote software updates on the components — and remote viewing of the components' web visualizations.



**Maple Systems offers CMT3092X that maximizes accessibility by allowing remote cellphone and tablet access.**

**A built-in server lets the HMI function as a gateway that joins the plant to the outside world.**

Touchscreen HMI's and controllers certified for AWS essentially leverage AWS to let connected edge devices such as sensors and actuators locally act on data they generate — and use the cloud for data management, storage, and analytics.

Anywhere an HMI connects to the cloud, it's likely working in some IIoT capacity to inform corporate analytics and continual operations improvements. That's true of automated installations involving one to hundreds of machines.



## HMI network and connectivity (continued)

### MAPLE SYSTEM HMIs AND IIoT PROTOCOLS

Protocols supporting IIoT functions including various forms of data communications and HMI connectivity with edge devices include:

- ☒ Open Platform Communication Unified Architecture or OPC UA
- ☒ Representational State Transfer or REST and its application programming interfaces (APIs)
- ☒ Message queuing telemetry transport or MQTT

MQTT — so core to many IoT connectivity structures — is a protocol supporting scalable communications between sensors and mobile devices. Any built-in device support for MQTT is useful because it's applicable in Amazon AWS IoT services. In addition, MQTT (like AMQP) is lean and standardized ... and MQTT can be implemented on gateway HMIs handling field-device data for onsite and cloud systems.

HMIs offering the most MQTT support are meant to be connected to value-added services for provisioning data that's been edge processed in third-party systems — and run on cloud services. Such HMIs can connect as a MQTT both a publisher or broker, and also manage data and connections with publishers or subscribers.

Interoperability standard OPC UA is also indispensable for leveraging the full promise of connected HMI technology. OPC UA includes publish-subscribe communications in its specification definitions, so can serve as an alternative to MQTT for data transport to the cloud

Those in motion control most value the standardized communication protocol of OPC UA complemented by time-sensitive networking (TSN) as a vendor-independent fieldbus for decentralized automation. OPC UA with TSN can even render additional PLCs unnecessary — as in machines employing integrated servomotors, for example. After all, more systems than ever now benefit from distributed architectures incorporating smart motors and other components capable of processing commands and executing tasks while communicating with other devices in real time. In some cases, the latter can include HMIs serving as edge gateways to handle some of the axes' process logic and connections to ERP systems and the cloud. Read more about how [Maple HMIs support MQTT](#).

## MAPLE SYSTEM HMIs AND SQL DATABASES

Employed in many IIoT installations is structured query language (SQL) — programming that allows synchronization of and access to data and event logs on MySQL and Microsoft SQL (MSSQL) database servers. This relational database management system is free, open source, and widely supported. It's also secure — so safely integrated into controller HMIs and panel PCs. One SQL benefit is IT personnel access that's more simply implemented than alternatives relying on controls (and usually necessitating additional hardware and software). That's true of system controls as simple as Raspberry Pis or as complex as PACs with IoT database interfaces.

In fact, SQL also works with some controller HMIs that collect and display machine data for easier monitoring and analytics. Connecting such HMIs to a MySQL database allows data collection, organization, and storage in flexible and trusted databases for easy access and optimized business operations.

Maple Systems' HMI configuration software simplifies use of MySQL on their Smart HMIs. A Database Server object in EBPro lets users employ the Smart HMI to access and put data in Excel spreadsheets (and tabular data in the files of other common software) to:

- ☒ Display information on the HMI screen
- ☒ Synchronize data and event logs to a remote MySQL server on the local network
- ☒ Manage that data on the server

In just a few steps, engineers can use MySQL and MS Excel to collect, analyze, and respond to the data — for more informed decisions and optimized operations. Read more about how [Maple HMIs support SQL databases](#).



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**IN CONCLUSION:** In this MI DesignGuide we reviewed the five most common HMI hardware variations that we offer, including Resistive Touchscreens, Capacitive Touchscreens, Headless HMIs, Open Source HMIs, and OIT-type HMIs. Plus our IIoT and gateway HMIs, Industrial PCs, and HMIs with local IO (HMI + PLC) solutions.

No matter what HMI solution you decide on, Maple Systems offers a variety of hardware and software solution that support HMI networking and connectivity at all levels. From local machine control to IIoT and SCADA solutions, including MQTT, Sparkplug B, Ignition, OPC UA, and SQL Database integration.

For more information on any of our solutions, contact our sales department at [sales@maplesystems.com](mailto:sales@maplesystems.com)





*IIoT unification with HMIs lets engineers integrate smart-factory equipment into superimposed SCADA, MES, ERP, and cloud services ... and blur boundaries between these systems for **information technology and operational technology (IT/OT) convergence**. That helps operations simplify system configurations, operational adjustments, and managerial actions — as well as optimize maintenance schedules. IIoT HMI technologies also support freer information exchanges between suppliers and end users.*