AVnu™ Alliance White Paper

Networking for Industrial Machine Building

Version 1.0 - 12/2014

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Executive Summary

Companies creating industrial machinery used for fabrication, assembly, and testing are constantly upgrading the capabilities of their machines to standout in a competitive market. Increasingly these upgraded capabilities depend on free flowing data within the machine and between the machine and the remote machine builder headquarters. This enables new business models focused on monetization of consumables or service. It also reduces the cost of machine customization, enables increases in machine availability, and can provide the end user with simpler integration into their facility and logistics systems. This free flow of information has been called the Industrial Internet or the Industrial Internet of Things (IIoT). IIoT is predicated on participation of all devices on a converged network and requires a different set of communication technologies than what has traditionally been used for the control network in the machine. The IEEE 802 (the standards organization who manages the Ethernet standard) and AVnu are working to create updates to standard Ethernet to support the converged network needs for high speed, reliable closed loop control, and remote data access over standard IT infrastructure.

About AVnu Alliance

The AVnu Alliance is a community creating an interoperable ecosystem of low-latency, time-synchronized, highly reliable networked devices using open standards. AVnu creates comprehensive certification programs to ensure interoperability of networked devices. The foundational technology enables deterministic synchronized networking based on IEEE Audio Video Bridging (AVB) / Time Sensitive Networking (TSN) base standards. The Alliance, in conjunction with other complimentary standards bodies and alliances, develops complete solutions in professional AV, automotive, industrial control and consumer segments.

Industrial Machines

Machines surround us and assist in nearly every aspect of modern life. Some of these machines are designed for consumer use such as the car in our garage, the phone in our pocket, or the washing machine in our house. However there are many industrial machines that the average consumer does not interact with on a daily basis that are used in materials production, power generation, device assembly, and health-care. These high dollar industrial machines are custom designed for their specific purpose and are optimized for throughput, precision, and availability. In the US alone, industrial machines are an over $200B market.

This competitive market has undergone an evolution in the last 30 years transitioning from primarily mechanical designs to mechatronic software driven designs. Today intelligent systems control multiple independent motion axes providing flexibility and minimizing mechanical maintenance. A modern industrial machine is a networked, coordinated system consisting of numerous axes of motion, multiple specialized sensors, cameras, and power contactors; all controlled by multiple high performance CPUs.

Companies creating these types of industrial machines face a variety of business pressures.

- **Customization**: Industrial production machines vary in price from thousands of dollars to over a million dollars for a single machine. The final customer often expects the machine builder to customize the machine operation to meet their specific needs. This may be integration of the machine into the other equipment in their facility, changes to physical dimensions, modifications to the HMI, or integration of additional hardware or software capabilities. Machine builders need to respond to customer modification requests while minimizing engineering expenses and avoiding service challenges down the road.

- **Competition**: The final customer's business is dependent on their industrial production machines. These machines create the products the company sells and increased throughput means more product revenue. In some industries these machines are also major cost contributors through energy usage. To remain competitive, successful machine designers are constantly improving their designs to increase throughput, reduce scrap, and improve efficiency.

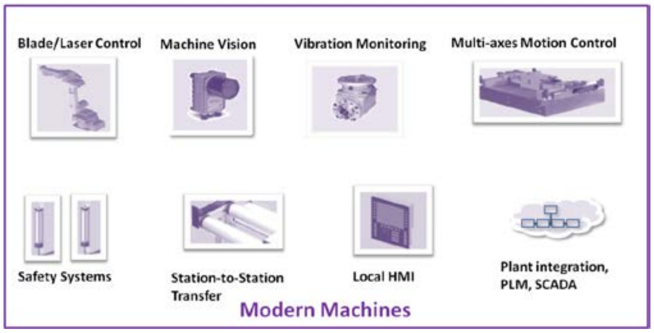
- **New approaches**: Beyond continuous improvement, there are also opportunities for radical changes in approach. In recent years machine builders have embraced new business models where they monetize based on consumables or on service. In these models the builder uses secure two way communication with the machine to provide just-in-time consumable supply and machine productivity based billing.

- **Availability**: End users are managing operational costs by reducing their maintenance staffs. This combined with the increased sophistication of the machines has created increased reliance on the machine builder to provide maintenance services. To meet this demand, machine designers create infrastructure for fault logging, remote debugging, remote reporting, and remote management. Remote management can eliminate the time and cost incurred from a technician travelling to the customer site and the remote reporting provides advanced warning of failures and can reduce unplanned downtime.

An Example – Semiconductor Machinery

For reference, consider equipment used for semiconductor production. Semiconductor production machines perform multiple chemical and photo lithographic steps where electronic circuits are created on a wafer of silicon. This wafer is then tested, cut into individual chips, and then the chips are packaged to provide electrical contact points and to allow for thermal management. The cost of producing and processing a silicon wafer is very high. To minimize the cost per chip, designers optimize the size of chips and the distance between the chips on the wafer. This, coupled with smaller 22nm and 14nm semiconductor processes, is allowing designers to pack many chips onto a single wafer. The step where the wafer is cut to produce multiple chips is called wafer dicing. To handle the tightly packed chips, the wafer dicing machine needs to make very precise cuts with precision measured in 1/1000 of a mm.

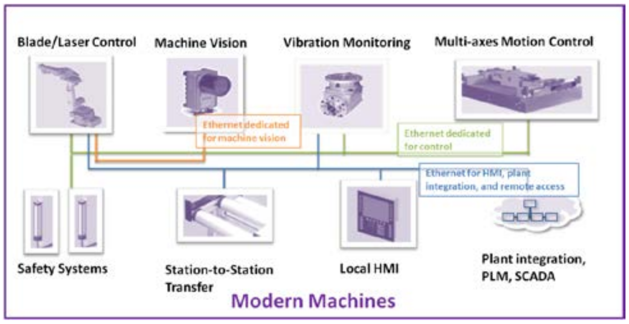
Examine in more detail the inner workings of a wafer dicing machine. To achieve the required dicing accuracy, a typical implementation uses precise dicing blades or lasers to etch and cut the wafer. This cutting is controlled with high performance motion control axes often using fast responding mechanisms like voice coil motors or multi-axes galvanometers for laser control. These axes get inputs from high resolution absolute position feedback mechanisms. Machine vision is now sometimes also used in the main control loop to assure proper position. These performance axes are sometimes also augmented with vibration feedback to adjust for small movements of the system. The sensors must be read by the controller, used as inputs into sophisticated control algorithms, and the cutting motion adjusted many thousands of times per second. This control loop must be deterministic and precisely timed. Around this core function of the machine there are additional tasks such as coordinated multi-axes motion to load the wafer and unload the cut chips. Many machines use vibration or power quality measurements as part of a predictive maintenance. The system normally has a local user interface where an operator can interact with the machine and has connections to the manufacturing logistics and enterprise systems.



Functions on a modern production machine

The design of this machine involves multiple processing, actuation, and input nodes. To minimize problematic and expensive point to point wiring, these nodes pass control data, configuration information, and process statistics across a set of communication busses. In most machines today there is a hierarchy of busses, each optimized for their specific function. Since the heart of the machine is the motion axes, examine these needs first.

To meet the stability and reliability requirements of high speed closed loop motion control, a motion bus needs to consistently deliver the control packets between the drives/sensors and the controller with a latency of <100 µS. The motion axes also need to be coordinated so time synchronization between the nodes of <1 µS is needed. Standard shared Ethernet cannot guarantee this performance as the potential queuing time in the switches will be too high. These fast control loops typically run on an infrastructure connected using Ethernet physical layer and CAT5 cabling but a using modified hardware in the nodes and bridges to eliminate queuing and provide latency bounding. Other discrete sensors and actuators are often also serviced by this motion bus. Cameras require very high bandwidth and can cause congestion problems on a shared media. Typically cameras will run on a dedicated standard Ethernet link, a USB 3.0 connection, or may use a vision specialized serial bus. The controllers and the HMI are connected using standard Ethernet and this same bus may be used to integrate the machine into the larger manufacturing process where it directly communicates with neighboring machines. This connection also provides integration into the overall plant MES system and mechanisms for remote connection to the original machine builder's maintenance and service systems.



Multiple busses to support machine operation

Technical Challenges

The system design using with multiple bus layers has led to a situation where Ethernet is common in control applications but where a typical machine supports multiple versions of Ethernet, each optimized to meet the requirements of a specific task. This technical approach leads to a set of challenges for the machine designer:

- **Bandwidth limitations.** Because many of the busses optimized latency by modifying the hardware layers, these busses do not directly benefit from the increased performance of standard Ethernet. Industrial adoption of 1-10Gb/S bandwidth allows control applications to share more data and incorporate more complex sensing such as high fidelity vision, 3D part or area scans, and vibration measurement.

- **Limited data within the machine.** The multiple non-interoperable busses in a high performance machine cannot directly pass data between them. Instead software services run on controllers or gateway devices to provide proxy and tunneling capabilities. Unfortunately these software services impose performance limitations and the lack of standardization makes configuration of data transfer difficult. Eliminating these barriers would provide increased performance and usability.

- **Limited remote access.** When a machine is malfunctioning at a customer facility, a machine builder greatly values the ability to easily probe all aspects of the machine to diagnose and repair the problem. To accomplish this they need to integrate cleanly into the end customer IT infrastructure and need to support a secure remote connection. This remote connection is most useful if it extends to the lowest levels of the device to get diagnostic data, real-time views, and to support reconfiguration tasks. The multi-bus design restricts the machine designer's access, potentially complicating and extending repair.

Beyond the benefits of simpler system integration, validation, and maintenance; there is increased value and urgency to eliminate the layers and barriers of traditional machine design. Today system designers are investing to incorporate IoT concepts into their systems to increase productivity, increase up-time, and improve other key performance indicators. Techniques such as remote system management, centralized data collection for big data analytics, and in-built self organizing machine to machine coordination, promise to radically advance next generation industrial control and monitoring systems. To support these capabilities, industrial designers need reliable, converged, remote, secure access to all the components and devices in their designs. This requires fundamental improvements to standard Ethernet so that it will concurrently support both industrial control needs and IoT connectivity and data access.

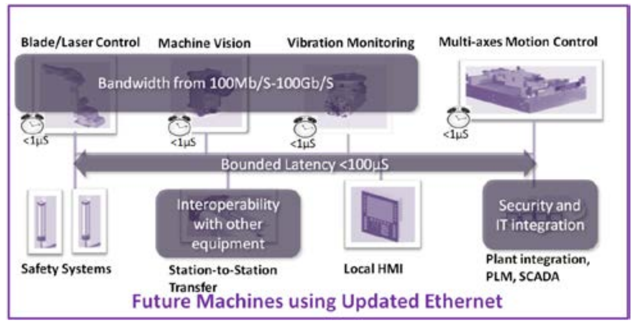
Updates to Standard Ethernet

Ethernet is defined in a family of standards referred to as IEEE 802. IEEE 802 is an open standards group with active participation from individuals around the globe. The IEEE 802 standards specify requirements for the different layers and functions of Ethernet and assure interoperability between different vendors. Much of the public is familiar with the work of 802.11, which develops the set of standards defining WiFi. Other relevant sets of standards include 802.3 which specify the physical and MAC capabilities for Ethernet, and 802.1 which specify the functions of Ethernet switches. Industrial suppliers, IT vendors, and silicon providers are collaborating in IEEE 802 and AVnu to create updates to standard Ethernet which will serve the needs of industrial machine designers by providing bounded low latency data transfer for control, shared synchronized time, and high bandwidth. With these updates, standard Ethernet will offer the industrial market:

- **Convergence:** One standard Ethernet backbone will support both low latency, high reliability control data as well as concurrent support other Ethernet traffic. Because the high reliability class of traffic is managed and protected, additions of other traffic cannot interfere with the control data and do not create the need for revalidation. This eliminates the data barriers and enables both in-machine data sharing as well and IoT capabilities for remote access. This also simplifies the engineering development process by allowing designers to all focus on the same core infrastructure.

- **Performance:** Standard Ethernet is constantly improved through large investment every year by both major silicon and IT companies and specialty protocol organizations. This has led to increased bandwidth, increased interoperability, and decreased commissioning time. The improvements to standard Ethernet to support control traffic will become part of this on-going technology investment. The control traffic class will support deterministic transfer measured in 10s of µS, time synchronization between nodes measured in 10s of nS, and automatic configurations for high reliability redundant data paths.

- **Cost:** The commercial use of Ethernet drives very high volumes and lowers the price of the components. By using standard Ethernet components, the cost of the end devices and the IT infrastructure is lower compared to using specialty Ethernet variants based on lower volume ASIC or FPGA based implementations.



Converged Ethernet to enable IIoT

The Role of AVnu

Many industrial application protocols have already been adapted to standard Ethernet. This does not mean they can coexist on the same network. Coexistence requires cooperation and this cooperation can occur at the end device, be forced within the network, or a combination of both. For the network to enforce coexistence then all network devices must be compatible. This level of compatibility requires interoperability specifications and certification testing much as the WiFi alliance has done for 802.11 and all its variants. AVnu as an organization can provide not only the labeling to give end users confidence, but also provide the specifications that are required to pull together the family of standards that will assure that networks can meet the demands of the various applications. To this end AVnu provides the following benefits:

1. Filling the gap between the standards and the specifications for network functionality that meets the needs of industrial applications
2. Certification of conformance to the standards and specifications
3. Driving industrial application needs into the standards process
4. Coordination of the various standards bodies
5. End user education and outreach
6. Education of regulatory agencies which affect compliance of critical infrastructure applications.
7. Open interoperable technology with multiple suppliers