ADVANTECH
Enabling an Intelligent Planet

Technical White Paper

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Advantech and EtherCAT

Combined technologies for increased market strength

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Introduction

Factory Automation in general and Motion Control as its most demanding sector are vital and indispensable elements in almost all industrial branches such as automotive, mechanical and semiconductor production, filling and packaging, printing and many more.

Motion control is a sub-field of automation, where position or velocity of machines and robots is controlled using motors or linear actuators. High performance factory and motion control depends strongly on a powerful communication technology. **Here, EtherCAT as Ethernet-based fieldbus is in a leading position and Advantech, a leading provider of automation control equipment and solutions, is on the way to support EtherCAT intensively.**

Fieldbus technology still in front

In the late 1990s, pushed by increasing market requirements, distributed digital control systems (named Fieldbus) have been developed to communicate a high volume of data in short time between a central controller and field devices (sensors, actuators, servos, drives, …) at the factory floor. Fieldbus got a generic term that encompasses a number of different industrial network protocols such a Profibus, DeviceNet, FOUNDATION Fieldbus and others. A PLC or PC serves as fieldbus master which communicates with distributed fieldbus slaves such as I/Os, transmitter, servos or drives. Allowed fieldbus topologies include daisy-chain, star, ring, branch, and tree. Compared to the pre-fieldbus era with single direct cabling between controller and each field device, fieldbus technology reduces length and number of cables, shortens installation time, simplifies maintenance and provides major advantages especially as intelligent field devices with diagnosis capabilities are connected. This successful fieldbus technology is still widely in use today.

Market demands boost Ethernet, …and EtherCAT

Since a couple of years, market requirements on automation systems further increased and demanded for more powerful solutions enabling more and faster data communication, higher time synchronization and determinism up to real-time behavior. The actual discussions about topics like *Internet of Things* and *Industry 4.0* describe what is expected from industrial communication systems in the near future. Fieldbus technologies, because of their limited bit rate, will not be able to meet these systemic requirements. Conversely, due to its ubiquity, high speed, simplicity, and low cost components, Ethernet is a promising technology to replace fieldbus for the long term. **However, as Ethernet has not been designed originally for real-time control, it is non-deterministic in its original form.**

Ethernet

Ethernet has been started in the 1970s as a joint project by DEC, Intel, and Xerox. It was a simple, bus-structured transmission medium between multiple data stations in a local area. The data rate was 3 Mbps in the beginning. In 1982 this first solution emerged to the IEEE Standard 802.3. Then, various development steps increased Ethernet speed to over 10 Mbps and to “Fast Ethernet” with 100 Mbps. Today, a data rate of 10 Gbps has already been achieved. The term "Ethernet" describes both the hardware of the transmission medium (cables, connectors, distributors, etc.) as well as the data transmission with protocols, transmission forms, packet formats etc. From a different point of view, Ethernet is an explicitly specified implementation of Layers 1 and 2 of the OSI Layer Model and is widely used through the application of different protocols on higher layers e.g., HTTP or SMTP, as known from the Internet.

Industrial Ethernet

Further developments on various layers of the OSI model with the objective of making Ethernet suitable for use in the rough environment of industrial automation succeeded in an enhanced Ethernet technology (Industrial Ethernet) that combines the given high speed with real-time capability and the suitability for use in harsh industrial environments. Special properties include robustly designed (industrial-grade) components, switched and full-duplex transmission and the usability of protocols which meet the special requirements of industrial applications, e.g. real-time capability. In the last years Industrial Ethernet-based real time communication networks have been established at the control level as system bus as well as at the field level in manufacturing industries. Meanwhile, Industrial Ethernet has become a de facto standard for industrial automation networks. It is now increasingly preferred in factory automation and motion control applications with protocols such as **EtherCAT**, PROFINET, or EtherNET/IP. In process automation, it is used as system bus in the control level, while the field level - for some reasons including installation in hazardous areas - is still served by fieldbus solutions..

In spite of standardization efforts, automation companies developed different application protocols which are supported by specific user and vendor organizations such as ***EtherCAT Technology Group*** **(ETG)** for EtherCAT, *Profibus & Profinet International* (PI) for Profinet or *OpenDeviceNet Assosiation* (ODVA) for EtherNet/IP. An actual market review of the overall industrial communication market (provided by HMS Industrial Networks) sees Fieldbus technology still in front with a market share of 66 % for new installed systems (with Profibus at the top position) compared to Industrial Ethernet systems with 34% but at a much lower growth rate of 7 % compared to Industrial Ethernet with 17%. The main drivers for introduction of Industrial Ethernet systems are higher overall performance and easy office network integration. EtherNet/IP, PROFINET and EtherCAT are close together in the top group of Industrial Ethernet-based networks, followed by Modbus-TCP and POWERLINK.

EtherCAT performs best

EtherCAT (“EtherCAT – the Ethernet Fieldbus”) is considered to be the fastest real-time Industrial Ethernet network available. Originally developed by the German Automation Company Beckhoff, EtherCAT is now supported and further developed by the EtherCAT Technology Group (ETG) with around 3000 members worldwide. EtherCAT provides, besides a number of other benefits, two features that are especially needed in motion control networks: very high data transmission efficiency combined with high speed and high accuracy clock synchronization. Details are:

- EtherCAT is an open, high performance Industrial Ethernet technology. Introduced in 2003, EtherCAT is internationally standardized since 2007 in IEC 61158 and 61784 and ISO 15745-4. This means anyone is free to use the technology in a compatible form but obliged not to change EtherCAT to suit his individual needs. By doing so, EtherCAT will remain both open and compatible. For further development, only the EtherCAT Technology Group is responsible.

- EtherCAT´s key functional principle is how it process Ethernet frames: Each node reads the data addressed to it and writes its data back to the frame already *while the frame is moving through the device (fig. 1)*. This overcomes Ethernet's system limitations as the data frame ("packet") is no longer delayed at every node. This leads to improved bandwidth utilization with one frame per cycle being often sufficient for communication. This makes EtherCAT very fast with excellent corresponding performance.

- With its flexible topology (line, bus, tree, star or any combination thereof) EtherCAT can support thousands of devices without any restrictions in topology. Fast Ethernet Physics allows a distance between two devices up to 100 m; greater distances are possible by using fiber optics. Hot connecting and hot swapping as well as redundancy are other important features.

- EtherCAT supports common Ethernet technologies without affecting the network´s real time capability. The "Ethernet over EtherCAT" protocol transports FTP, http, TCP/IP etc. Functional Safety is built directly into the bus. Thanks to the "Black-Channel" approach, it is also available for other bus systems.

- EtherCAT is suitable for both centralized and decentralized system architectures. It can support master-slave, master-master and slave-slave communication as well as incorporate subordinate fieldbus systems.

- The Distributed Clocks (DC) mechanism (fig. 2) is used to provide highly precise time synchronization between slaves in an EtherCAT network, which is equivalent to the IEEE 1588 Precision Time Protocol standard. By using distributed clocks, EtherCAT is able to synchronize the time in all local bus devices within a very narrow tolerance range. All EtherCAT slaves are provided with an internal clock which named as System Time. One EtherCAT Slave, usually the first slave, will be used as a Reference Clock and distributes its Clock cyclically.

- EtherCAT takes conformance and interoperability very seriously; in addition to requiring a conformance test for each device implementation, the ETG offers a wide variety of activities to ensure interoperability between EtherCAT master and slave devices.

Since 2009, the EtherCAT protocol portfolio also includes the EtherCAT Automation Protocol (EAP). Thus, EtherCAT also allows Ethernet communication between control systems, as well as to the supervisory systems. EAP simplifies the direct access of process data from field devices at the sensor/actuator level and also supports the integration of wireless devices. For the factory level, the base protocols for process data communication have been part of the EtherCAT specification from the very beginning. In 2009 ETG enhanced those with services for the parameter communication between control systems and for routing across system boundaries. Uniform diagnostic and configuration interfaces are also part of the EAP.

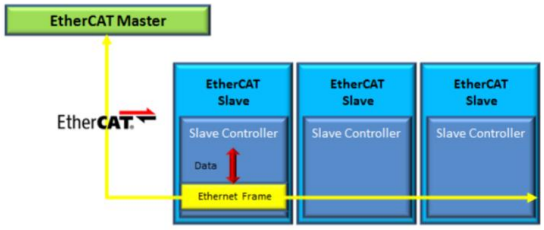

Fig. 1: Processing of Ethernet frames

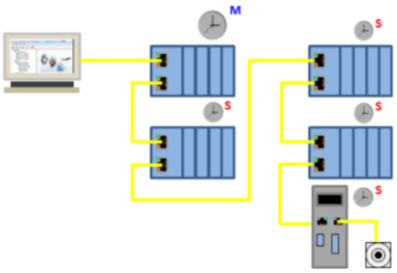

Fig. 2: Distributes clocks mechanism (M: Master; S: Slave)

Advantech is member of ETG and supports EtherCAT

Advantech is a member of the EtherCAT Technology Group (ETG) and supports EtherCAT technology increasingly with its products.
Founded in 1983, Advantech is a leader in providing trusted innovative embedded and automation products and solutions. Advantech offers comprehensive system integration, hardware, software, customer-centric design services, and global logistics support; all backed by industry-leading front and back office e-business solutions. Advantech has always been an innovator in the development and manufacture of high-quality, high-performance computing platforms. Advantech´s embedded devices have the ability to communicate, thus transforming simple dedicated devices into “Interconnected Smart Devices”.

In the Internet of Things (IoT) era, where wireless network is everywhere, intelligent systems require more and more storage and memory. In response to this trend, Advantech provides embedded M2M/IoT module integration services in order to minimize the workload of system integrators. Advantech provides a wide range of reliable sensor solutions for M2M communication including Bluetooth, Wifi, RFID and GPS modules. Edge computing platforms are also available with WSN and IP gateways. All of Advantech's intelligent devices and systems can serve as computing applications for data analysis.
Advantech's mission is to enable an intelligent planet with Automation and Embedded Computing products and solutions that empower the development of smarter working and living. With Advantech, there is no limit to the applications and innovations our products make possible.

EtherCAT links the field to the MES

In modern automation systems, open communication systems are required that provide data transfer from the field to the control level and from there to the enterprise level (fig. 3) and, as final stage, this information can then be directed to the cloud for further analysis.

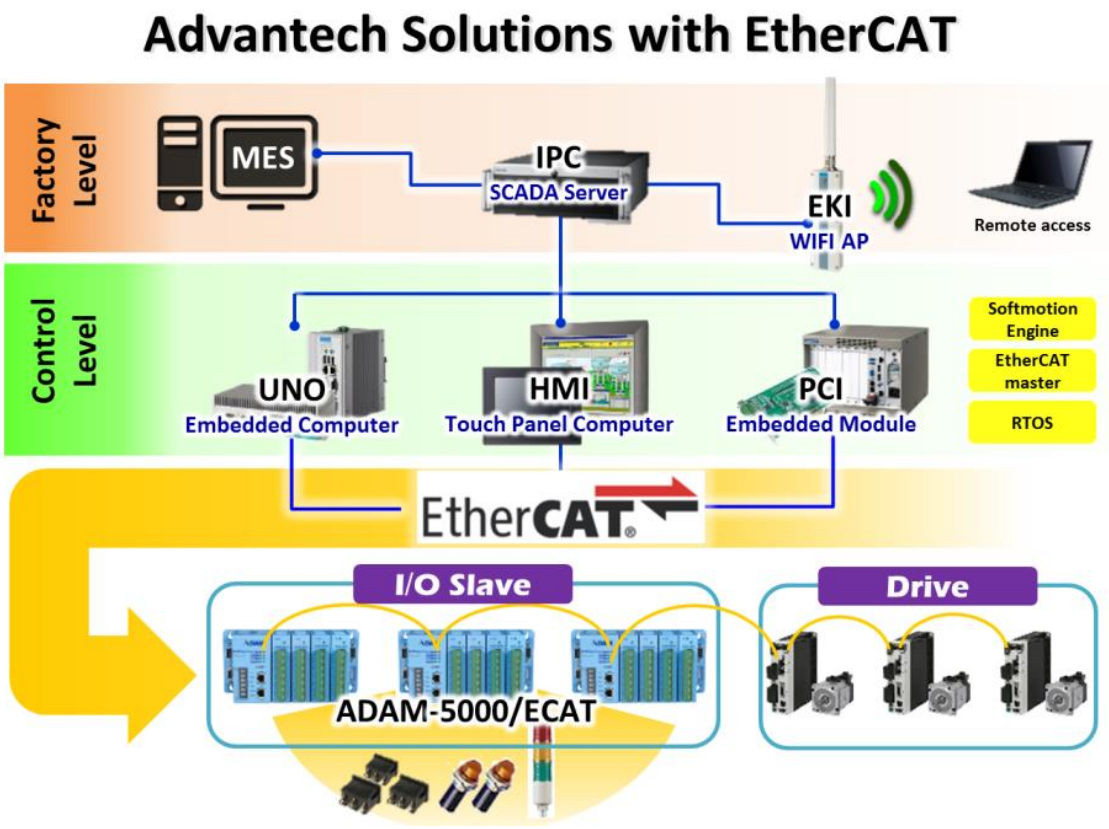

Fig. 3: EtherCAT links the field to the control and enterprise level

With the use of EtherCAT, Advantech covers the field and control level and from there, PC-based control solutions are very open with the Ethernet to connect to the factory systems (MES). With the standard Ethernet cables, all IO devices, drive/motors are well connected and synchronized within micro second update rate. Remote Access is possible using the EKI wireless device server. Communication to the cloud is managed by the SCADA Server with Advantech WebAccess/SCADA inside the IPC, see fig. 3, factory level, product in the center.

Advantech WebAccess+ is an Integrated Software Suite and Solution Platform for IoT (Internet of Things) applications. It combines WebAccess/SCADA, WebAccess/HMI, WebAccess/NMS (Network Management System), WebAccess+IVS (Intelligent Video Software) and WebAccess+IMM (Interactive Multimedia Software) in one suite.

EtherCAT supports Industry 4.0

Industrial automation will continue to grow and develop with the introduction of new technologies and concepts like the Internet of Things (IoT), machine to machine (M2M) networking, low-cost sensors, wireless connectivity, and others. Real-time communication systems will enable to run adaptive systems and provide multi-processing capabilities. New software applications will support wireless sensors and distributed peer-to-peer networks, small operating systems that allow nodes to communicate with each other. Factories and processes will be increasingly configurable and flexible. The vision of a fully automated future manufacturing enables customers to order online with electronic transactions while intelligent machines and robots smoothly and rapidly fabricate customized products in batch sizes down to one. This involves direct access through fast and reliable communication systems to all control components – controllers, switches, valves, motors,

drives etc. of the network. Required for that are high performance hardware components and communication technologies.

EtherCAT (ETG) co-operates with OPC

The above is a clear message to automation companies (such as Advantech) to provide appropriate hardware and to Networking Technology Groups (such as ETG) to provide the required enabling communication technology. EtherCAT - as a real-time-capable Ethernet-based fieldbus for machine and plant controls and leveraging the EtherCAT Automation Protocol (EAP) for data exchange - meets perfectly one of the core approaches of Industry 4.0, which is the *convergence of information and automation technology:* Seamless, Ethernet-based horizontal and vertical communication with real-time quality, as requested by factory automation, but without the complexity of most of the IT technologies. Even enhancing this concept, ETG and OPC Foundation have agreed just recently to co-operate in developing interfaces for the digital factory. Both organizations agree that their technologies complement one another: EtherCAT as the real-time-capable Ethernet fieldbus for machine and plant controls, providing the EtherCAT Automation Protocol (EAP) for data exchange, and OPC UA as a platform for scalable communication with integrated Security by Design, enabling encrypted data transfer up to MES/ERP systems and into the cloud.

EtherCAT enables Cyber Physical Systems

A Cyber Physical System (CPS) is a fundamental module of industry 4.0 and is composed of various physical and computing components that interact through embedded communication capabilities. CPS will gain increasing interest and importance in the manufacturing industry. In general, a CPS consists of two main functional parts: (1) *Advanced connectivity* that ensures real-time data acquisition from the physical world and information feedback from the cyber space, and (2) *Intelligent data management, analytics and computational capability* that constructs the cyber space. Information from different perspectives will be monitored and synchronized between the physical factory floor and the cyber computational space. By applying advanced analytics to this "pool" of information, networked machines will be able to perform more efficiently.

EtherCAT supports level 1 of the 5C-pyramid architecture

At today´s early development phase, there is an urgent need for a clear definition of CPS: A 5C-level architecture has been proposed for that as a guideline for implementation of CPS by IMS (Fig. 4, source: http://www.imscenter.net/cyber-physical-platform). At level 1, the "Smart Connection level", accurate and reliable data from the machines and their components are acquired and communicated to the cloud. This is the first step in developing a Cyber-Physical System application and EtherCAT is a powerful technology to support this step. The other 4 "C" level represent

- *Conversion level* for smart data analytics and conversion)
- *Cyber level* for creating the "twins" of the physical objects,
- Cognition level for self assessment and self-cognition and
- *Configuration level* for re-configuration of machines and components

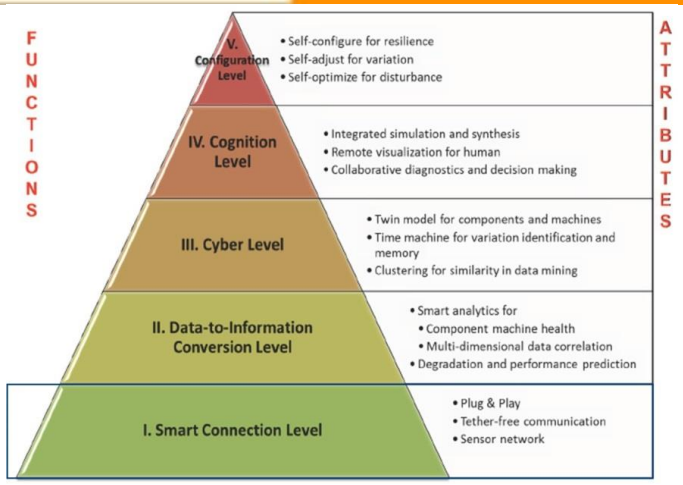

Fig. 4: The 5C pyramid for CPS definition (Source: http://www.imscenter.net/cyber-physical-platform)

PC-based motion and I/O control with EtherCAT

In the automation market, the PLC has been in a leading position since its introduction in the 1979s through today. Reasons have been its robustness and consistent performance in challenging industrial environments. The PLC evolved to include the capabilities of motion control, advanced PID process control and integrated safety, while also adopting some PC features such as a web server and networking utilities. However, beginning in the early 90s, the PC did also enter those markets by increasing processor technology and decreasing the costs of the components. The number of automation applications utilizing a PC is on the rise, causing further developments. Used primarily for complex calculations, monitoring, and measuring tasks and as a user-interface to the PLC, PCs stepwise included PLC functionality and became a more robust controller and evolved into what is known as soft-PLC. By adding a real-time kernel it is also able to support more critical tasking and control algorithms. On the other hand, also PLCs have been further developed with a built-in PC to enable simple operation requiring only keyboard and mouse to get started. So, rather than one technology winning over the other, PLC and PC-based control technology will coexist on the market and perhaps converge in the longer term. Advantech offers both solutions (fig. 5).

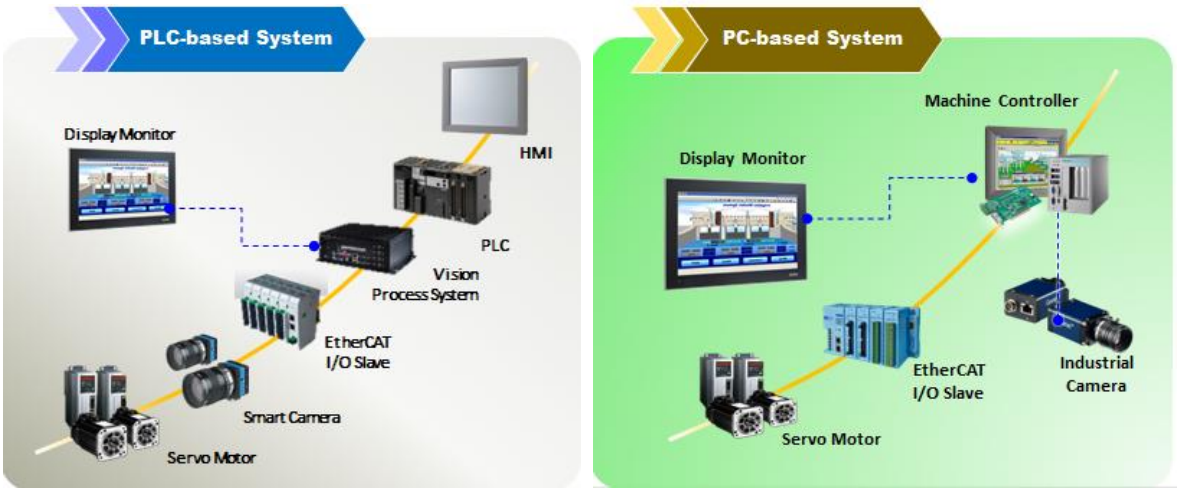

Fig. 5: Advantech´s PLC- and PC-based automation solutions

Complete EtherCAT-based automation solution

Advantech offers a complete, PC- and EtherCAT-based machine controller, including robot, CNC and general motion control (fig. 5, right). This solution offers high computing power from a scalable X86 CPU, a display for HMI, very low cost storage and memory. Besides I/O and Motion Control, this solution provides also machine vision control capability.

Advantech´s ADAM-5000 is an EtherCAT slave

With the ADAM 5000 controller line, Advantech offers a PC-based series of control equipment. This includes the ADAM I/O series with the **EtherCAT enabled version ADAM-5000/ECAT**. This EtherCAT slave is created by mounting a group of ADAM-E5000 series I/O modules on it. There are 4 slots on ADAM-5000/ECAT so that IO modules can be flexibly combined to achieve the optimum EtherCAT slave for the application with simple wiring and space-saving. EtherCAT functionality is integrated into the 32-bit ARM Cortex-A8 processors. These devices integrate an ARM processing core with a slew of other peripherals and interfaces that make them attractive devices for building industrial automation equipment.

Advantech´s EtherCAT-enabled components (Overview)

Implementing Master and Slave Devices
The interface for an *EtherCAT master device* has a single, simple hardware requirement: an Ethernet port. The implementation uses either the on-board Ethernet controller or an inexpensive standard network card. Consequently, with just a standard Ethernet port, a master device can implement a hard real-time network solution.

EtherCAT slave devices use inexpensive EtherCAT Slave Controllers (ESC) in the form of an ASIC, FPGA, or integrated in a standard microcontroller. Simple slave devices don't even need an additional microcontroller, because inputs and outputs can be directly connected to the ESC. For more complex slave devices the communication performance depends only minimally on the microcontroller performance, and in most cases, a 8-bit microcontroller is sufficient.

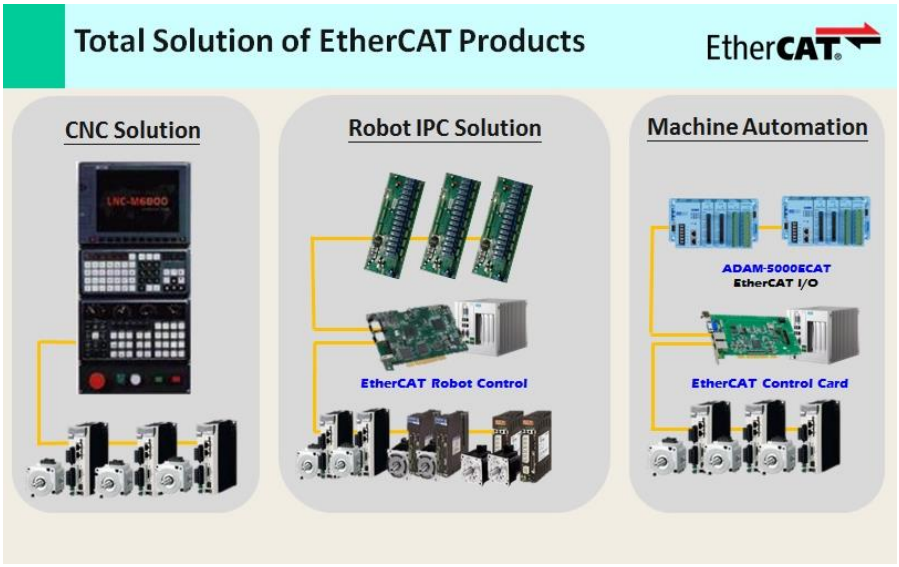

Fig. 6: Advantech´s EtherCAT products