Advancing Space Robotics with the EtherCAT Communication Standard

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The space industry is undergoing a transformation and has realized that sticking to proprietary technologies is a cost trap, while adopting proven standards will lead to success faster and at lower cost. This is especially true for space robotics and its communications technologies: Agreeing on a single standard makes particular sense here, as it leads to standard components that benefit all space robotics manufacturers. This paper discusses the fieldbus requirements of space robotics and shows how EtherCAT - the world standard for motion communication - meets these requirements.

I. Introduction

Service robot systems differ from their ancestors, the industrial robots, by the extensive use of internal and external sensor data, by kinematics with 7-DOF and more, and by interaction in close proximity to other technical systems or even in cooperation with humans. From a technical point of view, this requires powerful control and communication. Moreover, feedback control of soft robotics requires advanced real-time capabilities and strong determinism in communication. For systems with higher softness and improved responsiveness, sampling rates of more than 1kHz are required. Today, these robotic systems are creating new markets for robotic and maintenance systems.

At the same time, the space industry is increasingly demanding dexterous robots, and the range of applications is as diverse as on Earth. Robotic arm-equipped rovers for (semi-)autonomous exploration of foreign planets will be the extended arm of scientists, so performance must be comparable to that of human arms. Mid-term on-orbit missions and concepts rely on the use of many robotic arms of varying size, dexterity, and performance. Orbital services, repair and maintenance are the buzzwords of today. Assembly in space is the latest challenge.

From a functional point of view, there is no real difference between robotic services on Earth or in space. So, it is a reasonable approach to rely on the experience with robotics and automation on Earth. The technology is proven, is used worldwide, is standardized, is inexpensive relative to the tasks, and there are sufficient human resources available. Incorporating automation technology will provide the space industry with new opportunities at lower costs.

Autonomous assembly of large structures in space is a key challenge for future missions that will require structures too large to be transported in one piece. The James Webb Space Telescope has reached this limit, and the next generation of telescopes expected by astronomers, such as the High-Definition Space Telescope, will therefore require new assembly technologies, particularly autonomous robots. The need for large structures in space extends beyond telescopes to solar arrays for power plants, light sails to reach the outermost regions of the solar system, or heat shields for landing on Mars.

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The current state is that while a variety of space-specific communication technologies exist, most of them only partially address the increasing communication performance requirements (speed, latency, determinism) of impedance-controlled space robots, which is intensified by the transition from single-axis consideration to complex, centrally controlled kinematics. No standard drive profiles are available for software implementation, so each implementation reinvents the wheel.

In addition to technical limitations, most existing communication technologies for space applications have strategic disadvantages for use in space robotics, such as dependence on one manufacturer or slow development and lack of availability of standard components.

As a result, more and more players in this growing market are realizing that the communication technology is not an appropriate differentiator and are instead turning to technologies from general robotics to simplify and accelerate the development and testability of space robotics. Of course, these data bus technologies must also support the overall system avionics architecture to satisfy the mass, power, volume, reliability, and flexibility requirements imposed by mission needs.

II. Technical Requirements to a Communication Standard for Space Robotics

A. Performance

The core functionality for space robotics applications is motion control, and the performance requirements of space robotics applications are now comparable to those of robots on Earth. Although the motion speeds in space are typically lower, the extreme lightweight nature of the systems means that they are less rigid and therefore require highly dynamic control with low system delay. This requires cycle times down to well below one millisecond and precise synchronization accuracy for equidistance of position sensing and synchronization of multiple degrees of freedom (DOF) systems, since space robots are no longer considered as individual axes lined up in a row, but as an overall system moving dynamically and synchronously.

B. Topology

Space robotics applications require a network structure that can adapt to dynamic configuration changes, such as adding payload tools, sensors, cameras, etc. to a robotic system. The data bus must accommodate a changing network topology by automatically detecting, addressing, and communicating with added nodes with minimal delays in network initialization and hardware configuration changes.

C. Environment

A communication system for space robotics must be able to meet the extended requirements for radiation resistance, temperature, shock, vibration, etc.. These result from the character of the mission and therefore cannot be quantified in general terms.

D. High Availability

High availability is naturally of much greater importance in space. System reliability requires different levels of redundancy depending on the mission: from cable redundancy to controller redundancy to independent primary and secondary networks. A communications technology for space robotics must support these features. Ideally, a technology will support cross-strapping between primary and redundant network nodes with a minimum of cabling and switches, allowing robotics to operate with any combination of primary and redundant channel nodes, improving system reliability and reducing the impact of single node failures.

E. Integrated solutions

Development, qualification, debugging, cost and time can be saved by communication technologies that provide the node implementation with an FPGA IP core. An FPGA-based implementation offers the following advantages:

1) Radiation-tolerant hardware availability: technologies that provide IP cores for the radiation-tolerant path to flight FPGAs significantly reduce the development time and cost associated with qualifying an ASIC for the in-flight radiation environment.
2) Low Utilization: The lower the FPGA utilization for the IP Core, the more headroom available for the application specific controller logic.
3) Small Circuit Card Footprint: By combining the node controller with application specific firmware in the same FPGA, developers can optimize the electronics circuit card assembly (CCA) form factors that support the volume constraints of the assembly.

F. Verification and Testability

Space systems and their interfaces must be tested very carefully, since implementation errors cannot be corrected during operation, or can only be corrected with great difficulty. The testing effort therefore usually exceeds the actual implementation effort, even for the communication interfaces. This can be reduced considerably if the bus technology provides extensive and proven conformance test systems.

G. Flexibility of test set-ups

Space technologies need to be replicated on a high-fidelity ground-based test bed that will be used to exercise, verify, test, and debug the system during development or flight. Additional sensors should be easily integrated into the overall system in a time-synchronized manner. A technology that has supporting test equipment and low-cost, off-the-shelf hardware/software for implementing the communications bus architecture in a ground-based test bed is preferable to a technology that requires the time and expense of more specialized or custom GSE development.

H. Interfacing to other communication systems or data sources

It is often necessary to integrate subsystems using other bus technologies – such as grippers or equipment for test set-ups – into the robot control system. It must also be possible to integrate the robot itself into other environments. Therefore, the availability of interfaces to other bus systems is an essential requirement. It would be advantageous to be able to transmit data from additional sensors or cameras that are not part of the robot system itself without jeopardizing the real-time properties: This would avoid additional cabling.

I. Cables with low torsional stiffness and rigidity

Space robots operate under gravity-free conditions and thus with low forces, so interference from inflexible cables should be largely avoided. Therefore, the availability of communication cables with low stiffness and torsional stiffness is important.

J. Safety

Communication-integrated functional safety according to IEC 61508 is only slowly making its way into space robotics. So far, people rarely stay in the working area of the moving robot in space, so a simple shutdown is usually sufficient for personal protection, also thanks to the relatively slow movements combined with the low forces generated by robots in space. However, it is foreseeable that this will change. Therefore, a communication system for space robotics should, in principle, support integrated functional safety.

K. Security

Cybersecurity is gaining importance everywhere, so it would be reassuring if the space robotics bus system has no vulnerabilities in this regard.

III. Strategic Requirements to a Communication Standard for Space Robotic

The strategic requirements for a communications standard for space robotics are less detailed than the technical ones, but equally important:

A. Openness

Open access to technology avoids dependence on single suppliers and is therefore a key strategic requirement for a space robotics bus system. Ideally, openness extends beyond the space industry to increase supplier diversity and ensure the dynamics of technological progress. The technology should therefore be an international standard.

B. Large Community

Only when bus technology is backed by a large community is there broad support for suppliers of space robotics components and systems. In addition, a large community of supporters leads to long-term availability.

C. Stability

Technical progress, improvements and functional enhancements are important and necessary, but should preferably not be accompanied by new incompatible versions of the technology. Communication systems in particular are known for sacrificing stability for improvements and generating versioning problems. However, this is particularly problematic for space applications because development cycles are relatively long.

D. Cost Effectiveness

Costs are also playing an increasingly important role in space applications, and it goes without saying that the robotic bus system must contribute to cost savings.

E. Proven in robotics

A technology for space robots should already have proven itself in other robotic applications. This is a matter of common sense but is not always taken into account.

F. Roadmap

Even if a bus technology already must meet all technical and strategic requirements today, the existence of a technology roadmap would be helpful because it suggests that future requirements can also be covered with the same solution.

IV. The unique EtherCAT Functional Principle

A. The Ethernet real-time challenge

Ethernet provides a robust and space proven physical layer and a data link layer with good error detection mechanisms that can host a virtually unlimited protocol variety. However, IT-style Ethernet lacks determinism and has poor bandwidth utilization for small process data units such as those needed to control drives. In addition, large protocol software stacks in the network nodes not only increase complexity and thus error-proneness and local processing delays, but also require computing power and memory, which is especially undesirable for space applications. The determinism issue can be addressed by extensions of switches combined with complex traffic planning, and the bandwidth issue by higher bit rates, but these have disadvantages in terms of robustness.

B. EtherCAT approach: Processing on the fly

EtherCAT takes a different approach with its unique functional principle of "processing on the fly". Instead of sending a separate Ethernet frame to each connected device and receiving a response frame from each device in every communication cycle, the EtherCAT controller sends one single frame containing all process data through all devices, and each device extracts its output data from this frame and inserts its input data into the same frame (**Fehler! Verweisquelle konnte nicht gefunden werden.**).

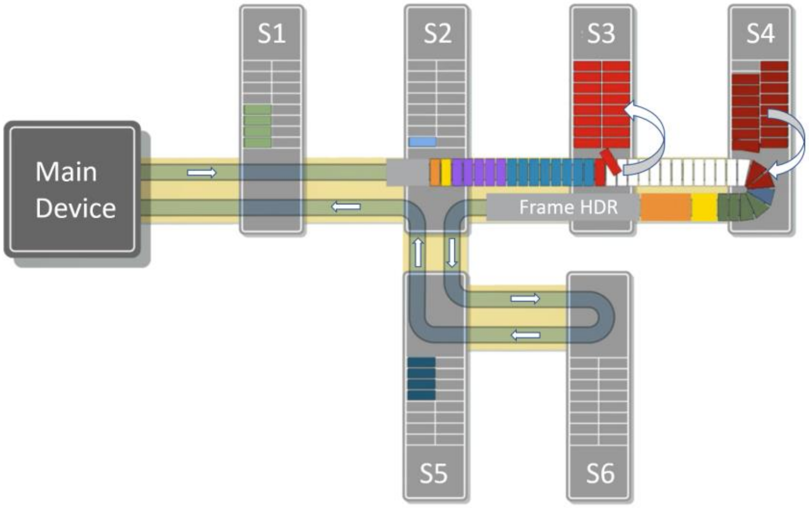

Fig 1. EtherCAT functional principle: Ethernet frame processed "on the fly"

Distributed clocks in the devices are synchronized with the very same frame in such a way that the sending determinism of the frame has no influence on the synchronization accuracy. The frame contains the clock time of the first device which is latched by the subsequent devices and used for adjusting the local clock. (Fig. 2)

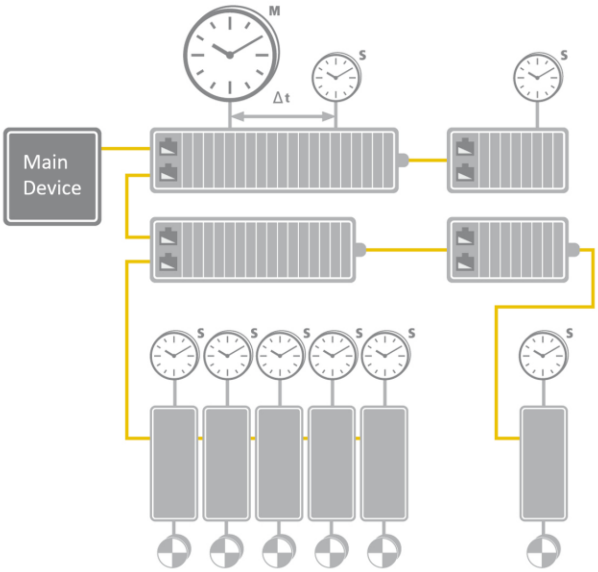

Fig 2. Synchronization by Distributed Clocks

The EtherCAT functional principle results in maximum performance through the best possible use of bandwidth and at the same time leads to highly accurate synchronization of the connected devices (Fig. 3)

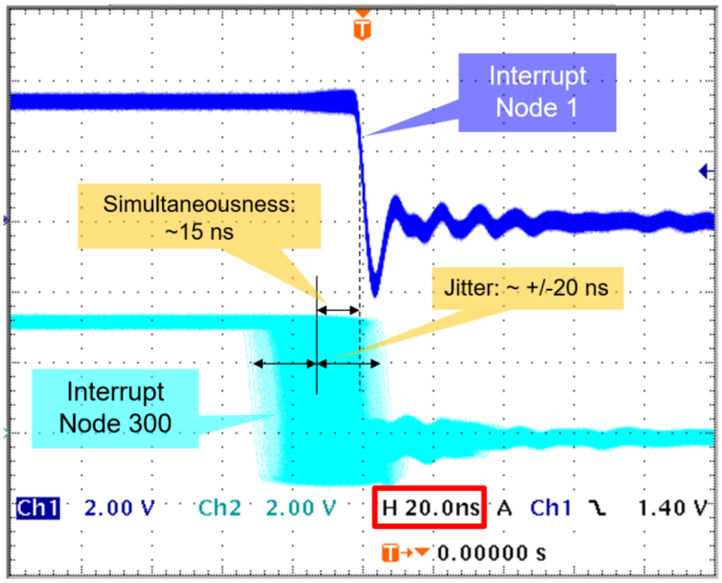

Fig 3. EtherCAT accuracy: Scope view of two devices with 300 nodes and 120m of cable in between

But not only that: it lowers the complexity of Ethernet below the level of classic fieldbuses without limiting the Ethernet capabilities, since EtherCAT can also transmit any IT-protocols such as TCP/IP in addition, if required, without diluting the real-time properties. EtherCAT does not require large software stacks because the key functionality is implemented in the EtherCAT chips in hardware. For the network master no special chips are needed. An Ethernet MAC with lean software is sufficient as the master typically only sends one standard Ethernet frame per cycle and receives one.

Neither switches nor their configuration are required, which also means that EtherCAT supports the line topology without the limitations imposed by cascaded switches.

V. How EtherCAT meets the Technical Requirements

A. Performance

EtherCAT is known as the fastest industrial Ethernet technology because its functional principle makes optimal use of the available bandwidth. Typical cycle times start at 50µs and 100 drives can be updated every 100 µs. The distributed clocks synchronization mechanism results in a jitter of less than 100ns, which is also achieved in networks without a precision clock in the master. The nodes share the clock time already present in the chips. The system scales very well so that additional nodes have minimal impact on latency, which is appreciated by any control software architect.

B. Topology

EtherCAT supports arbitrary topologies without compromising performance and without the complexity caused by cascading switches or hubs: line, tree, star topologies can be freely combined (Fig. 4). There can be up to 65,535 nodes per segment. One master can host multiple segments. EtherCAT main devices can automatically detect network changes by using topology detection, which compares the actual network with the configuration expected by the master and can reconfigure accordingly. This allows nodes to be connected and disconnected during operation. Dynamically adapting network discovery allows network segments or individual nodes to be switched on and off during operation, for example when a robot manipulator accesses and connects to specific EtherCAT-based sensor tools.

EtherCAT subdevice controllers form the basis for this hot connect functionality. EtherCAT automatically assigns addresses to the subdevice nodes so that no manual addressing is required. This is a great support for the changing configurations of robotic manipulators, where robotics needs to extend its internal data network to include external gripping loads and/or sensors. Addresses can be maintained, so no new addressing is required when more nodes are added, as addresses are automatically assigned at startup.

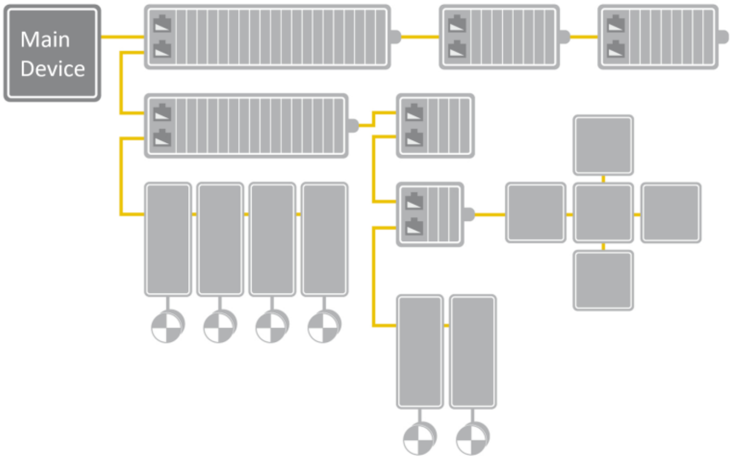

Fig 4. EtherCAT supports any combination of line, star and tree topologies

C. Environment

Chips with EtherCAT slave controller functionality are already available from 12 semiconductor manufacturers: including those for extended environmental requirements such as temperature, shock or impermeability. A Beckhoff EtherCAT ASIC type was put through extensive irradiation tests in preparation for ISS missions (LEO) and was found to be suitable for space use. In addition, there are three different FPGA manufacturers for whose devices an EtherCAT IP core is available: Xilinx, Intel and Microchip - also for the respective radiation-tolerant and radiation-hardened space grade devices. Thus, EtherCAT semiconductors are available for the full range of space mission requirements.

D. High Availability

EtherCAT achieves cable redundancy by the ring topology without the network nodes or their chips having to have special properties. If a neighboring node (or tool) is removed from the network, the port is automatically closed so the rest of the network can continue to operate. Very short detection times < 15 µs guarantee a smooth transition. This also prevents the limitation that a failure in one node can disable the whole segment. Master redundancy with hot standby is also possible. EtherCAT can detect topology changes due to failures, disconnection, or addition of slaves with a node discovery method by querying the nodes through the network whereas the nodes not only respond with their identification, but also with information regarding the connection status of each port. Hence, this ability to automatically reconfigure to accommodate changing nodes in the network supports the operational demands of space robotic applications. Furthermore, the network nodes can be equipped with several EtherCAT chips to achieve multiple redundancy (Fig. 5) - the combination of all these possibilities is used e.g. by NASA 0.

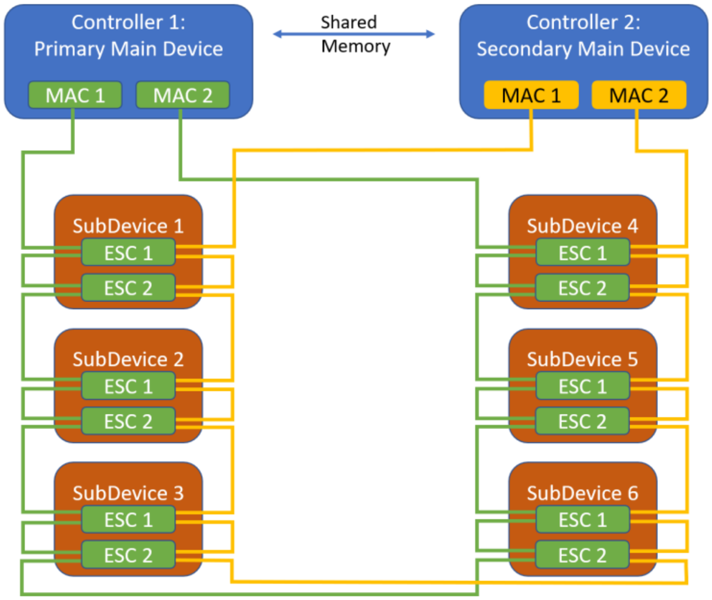

Fig 5. Multiple Redundancy supported

E. Integrated solutions

The chip variety of EtherCAT also includes highly integrated devices with a wide variety of peripherals, CPU/µC cores and memory. The flexibility is naturally even greater with the FPGA solutions. The exact functional scope of both the EtherCAT IP core and the other features can be adapted exactly to the requirements, thus reducing the number of components on the circuit board and its size and weight.

F. Testability and Verification

Well-functioning interoperability is the prerequisite for the success of an open communication technology. That is why the EtherCAT Technology Group has placed emphasis on testing and certification from the very beginning. The comprehensive EtherCAT Conformance Test Tool (CTT) tests devices with well over 1000 test cases for compliance with the standard, and accredited EtherCAT test centers in North America, Europe and Asia issue official test reports, on the basis of which the ETG issues certificates of conformance. The CTT can also be extended by the developer with additional test cases, which can be used e.g., in a consortium to test specific functional extensions.

G. Flexibility of test set-ups

Thanks to the openness of the technology and the great acceptance in the market even beyond space and aerospace applications, COTS devices are available for practically all requirements of e.g., test set-ups. For example, there are well over 1000 different I/O devices for virtually all signal variants and in many form factors, and a similar wide variety of drive components. EtherCAT controllers support all common programming languages, and tools such as Matlab Simulink. This allows prototypes and test setups to be implemented flexibly and quickly. Thus, EtherCAT comes fully equipped with plug and play test bed solutions that provide a wide suite of system diagnostic features and tools which can help detect and locate errors or track performance.

H. Interfacing to other communication systems or data sources

The efficient bandwidth utilization of EtherCAT allows to tunnel other protocols over the network. These can be individual telegrams/frames or entire process images of fieldbus systems. With "Ethernet over EtherCAT" (EoE) any Ethernet protocols are tunneled via EtherCAT without affecting its real-time properties. The mapping of fieldbus gateways to EtherCAT is also standardized within the ETG, so that the process data and parameters are transferred consistently, and the controller does not have to differentiate functionally between native EtherCAT devices and devices connected to underlying bus systems. There are now gateways to 35 different fieldbus systems.

I. Cables with low torsional stiffness and rigidity

EtherCAT does not change the 100BASE-TX Ethernet physical layer. 100BASE-TX cabling provides a low conductor count, a small cable outer diameter and associated bend radius to minimize volume impact for a robotics assembly, and EtherCAT be operated with the entire variety of corresponding cables. This also includes very flexible and bendable cables as required for space robotics. Optical fibers according to 100BASE-FX are suitable for large expansions and special requirements. EtherCAT P also provides a solution for nodes that are to be supplied with data and power via a single line: 2 x 24VDC/3A and full-duplex EtherCAT communication are transmitted via 4 wires. For higher power there are hybrid cables with additional wires.

J. Safety

An additional level of reliability is achieved with the protocol extension "Fail Safe over EtherCAT" 0 (FSoE also known as "Safety over EtherCAT). The TÜV approved protocol has a proven residual error probability of < 10-9/h and meets the requirements of Safety Integrity Level (SIL) 3 with single channel communication, whereas SIL4 can also be achieved with additional measures. A well-developed ecosystem including a TÜV-certified test tool facilitates implementation, and Safety over EtherCAT also meets the more stringent requirements of the latest edition of IEC61784-3 without modification.

K. Security

EtherCAT is inherently hardened against cyber-attacks: The protocol is not based on the Internet Protocol and thus eliminates almost all attacks from the outset. Non-EtherCAT frames are filtered out in hardware by the EtherCAT chips. Additional unwanted EtherCAT nodes cannot communicate unless actively enabled by the master, and topology modifications are also recognized by the master. Unused ports are switched off by the master so that unintentionally connected nodes cannot cause any damage. EtherCAT is therefore secure without the complexity of certificate handling.

VI. How EtherCAT meets the Strategic Requirements

A. Openness

EtherCAT is an open standard that can be implemented and used by anyone. As an IEC standard EtherCAT 00, the EtherCAT drive profile 0 and Safety over EtherCAT are internationally recognized. In countries where IEC standards are not automatically acknowledged (such as China and South Korea) EtherCAT is also a national standard 00. The specification is available in English, Chinese, Korean and Japanese.

B. Large Community

EtherCAT is supported and maintained by the EtherCAT Technology Group (ETG). With over 6800 member companies from 70 countries 0, ETG is the world's largest fieldbus organization. Several hundred of ETG's members are active in the space and aerospace sector.

C. Stability

ETG has succeeded in advancing EtherCAT without versioning issues known from other communication technologies: with EtherCAT new features have been added without changing the existing ones. Older devices can be easily replaced by newer ones without having to consider network protocol versions. This provides a stability of the technology that is second to none and ensures long-term availability and investment security.

D. Cost effectiveness

The costs are primarily determined by two factors: Vendor variety and implementation complexity. A large variety of vendors ensures low prices and fully featured products. EtherCAT has the widest vendor and product variety of all Industrial Ethernet solutions. Over 3000 vendors have registered as official EtherCAT suppliers, offering the full range of products for any type of application. Simple implementation is particularly important in space programs, as it reduces the probability of errors. With EtherCAT, the complex part of the implementation is embedded in the chips and not in the stacks. The chips (including the IP cores) are deployed in many millions of nodes and are very mature. The EtherCAT protocol stacks are extremely lean – also on the controller(master) side and have successfully implemented in thousands of products. The availability of tools from different manufacturers additionally contributes to easy implementation and thus to cost reduction.

E. Proven in robotics

EtherCAT is the leading industrial Ethernet motion bus system used by many robot makers. Industrial, medical, and humanoid robots can meanwhile be divided into three categories regarding the communication systems used: its either EtherCAT, or they still use CAN, or self-developed technologies from the time when EtherCAT was not yet available. All other bus systems no longer matter.

A prominent example is Kuka, the market leading robot supplier to the automotive industry: All Kuka robots have been EtherCAT robots since 2010.

F. Roadmap

EtherCAT is proven and mature a million times over, but it is far from the end of its possibilities: ETG is working on the next fully backward compatible extension: with bit rates of 1 Gbit/s and more, EtherCAT G provides even more bandwidth. A focus of this development is the seamless integration of 100 Mbit/s EtherCAT networks, so that current devices and developments will not become obsolete or redundant through EtherCAT G.

EtherCAT G ensures that in 25 years EtherCAT will still be the technology of choice for fast, deterministic communication in control applications.

VII. Proven in Space Applications

A. EtherCAT on ISS

EtherCAT has been used in space applications since 2015. It is permitted to report about the project "Kontur 2"0, a joint project of the German Aerospace Center DLR and the Russian Federal Space Agency ROSCOSMOS, as well as about the „Haptics-2” flight experiment within the METERON project 0 of the European Space Agency (ESA) in conjunction with NASA. In both projects an EtherCAT equipped joystick was deployed to ISS, and EtherCAT was selected for its determinism, its openness, and the radiation robustness of the ET1100 EtherCAT Slave Controller chip, which was tested extensively with different radiation sources and doses 0.

B. PULSAR

The multi-national team of the EC-funded project PULSAR 0 has developed a robot system for demonstrating the on-orbit assembly of a space telescope. One demonstrator of Pulsar was set-up by the DLR Robotics and Mechatronics Institute. The EtherCAT based robotics demonstrator is a KUKA KMR iiwa Mobile Manipulator with some additional sensor systems.

Such assembly tasks as demonstrated in PULSAR require an impedance-controlled robot arm, like the iiwa robot arm.

C. CAESAR

The DLR Institute of Robotics and Mechatronics has developed the CAESAR 0 arm, based on the same technology as iiwa. The 7dof robot arm (Fig. 6) is equipped with torque sensors in each joint, intelligent joint control units and EtherCAT as the fast, deterministic communication system.

CAESAR is a robotic system designed for commercial space applications. It brings the advantages of terrestrial lightweight robots and the philosophy used in the development of cobots to orbit. Based on joint torque sensing capability, complex joint state control, and Cartesian impedance control at the tool center point, it is capable of handling any type of activity required in on-orbit servicing. Pick-and-place operations, docking and berthing, manipulations, up to maintenance and refueling are possible with the required reliability and robustness. Small deviations in the scenario or short-term changes in the contact forces that occur are handled by the robot arm controller.

To accomplish that the dynamic behavior of the robot's end effector can be adapted in stiffness and damping to match the requirements. Even in unexpected Off-Nominal situations like collisions with the robots structure a risk minimizing strategy to stop the maneuver is possible as the sensory information is available all over the arm in each of the joints.

To implement all of these features a reliable real-time exchange of measured and reference values, adaptable limits, control and performance parameters as well as housekeeping data has to be guaranteed. A mission specific base power insulation unit adapts the robots necessary supply to the spacecraft.

By integrating an additional EtherCAT slave at the last joint and programmable logic various interfaces to end effectors, lighting units, tool changers and even camera systems can be realized without additional cabling inside the robotic arm.

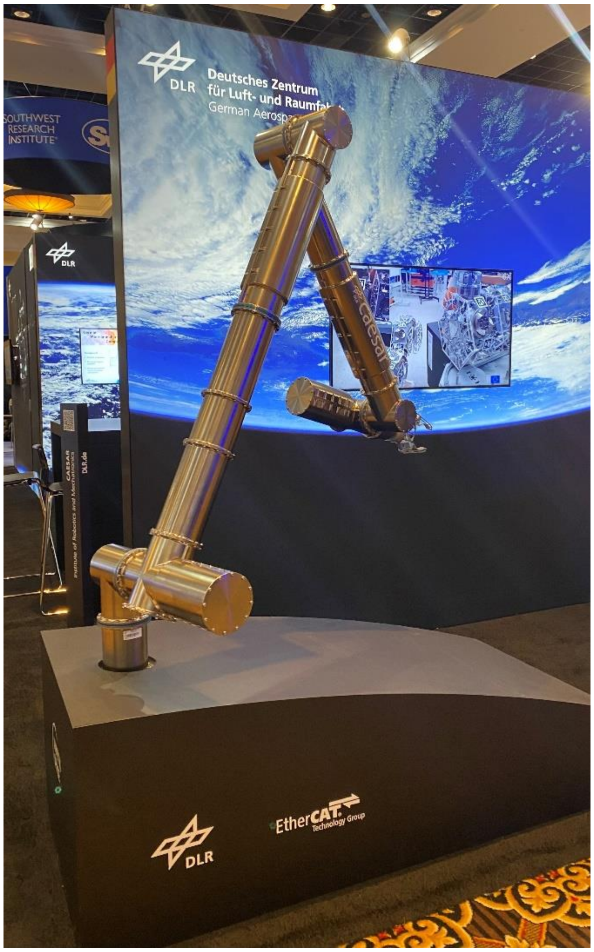

Fig 6. DLR CAESAR on exhibit at 2022 Space Symposium, Colorado Springs, CO

D. xLink™

Motiv Space Systems has developed an affordable, modular robotic system for use in a variety of space environments called xLink™ (Figure 7). Its first deployment will be on NASA's OSAM 2 mission where it will assist with assembly and manufacturing tasks in Low Earth Orbit. In addition to serial communication, often found on today's spacecraft, Motiv is actively working to also enable xLink with EtherCAT as it has done with its ground-based robotics (RoboMantis).

The xLink robot has a distributed control architecture, joint-level torque sensing, a distal 6-DOF force torque sensor, and its scalable architecture means it can be adapted to use cases ranging from Intra-Vehicular Robotics where it might be tending a science experiment to Extra-Vehicular Robotics activities where it might be assisting with berthing a spacecraft. In addition to adding EtherCAT as an optional configuration for xLink, Motiv is also enabling xLink with SpaceROS (a version of the Robot Operating System for space flight) which follows the themes raised in this paper of the openness and robustness of EtherCAT implementations.

EtherCAT will improve the overall performance and flexibility of the system for the points raised in this paper and will enhance its utility through enabling dynamic reconfiguration of the robotic system on orbit. Additionally, these features will allow for xLink to safely work next to astronauts in future collaborative robotics activities.

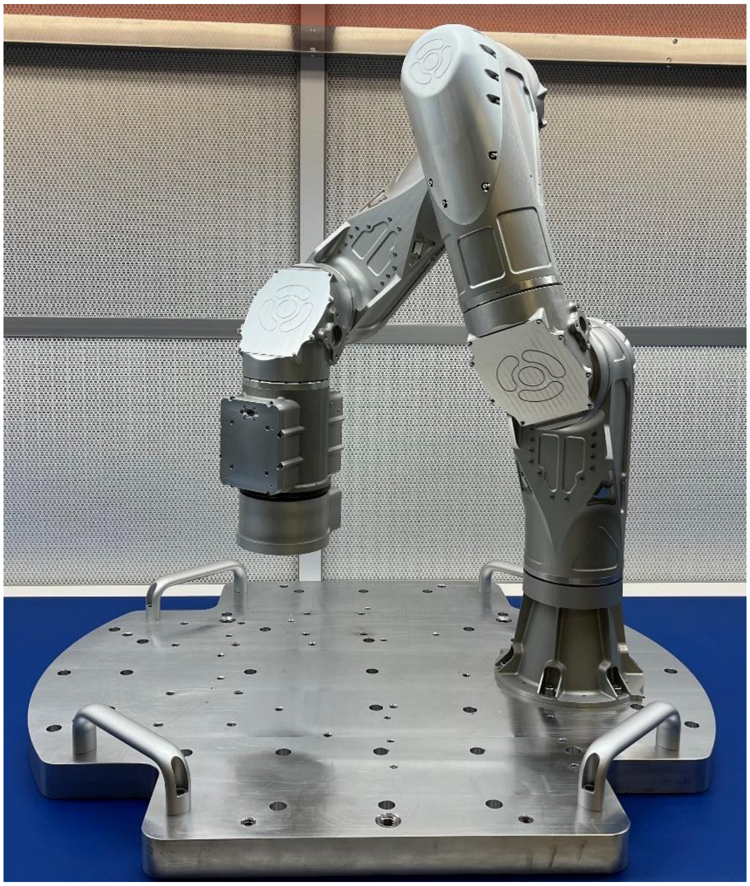

Fig 7. Motiv Space Systems' xLink 7-DOF flight robotic arm

VIII. Conclusion

Space robotics applications require data bus technologies that not only support the real-time deterministic performance and data rate requirements of internal control loops, but also support the overall system avionics architecture in meeting the mass, power, volume, reliability, and flexibility demands imposed by the mission requirements.

Space applications such as robotic manipulators need to minimize the impact of the mass, stiffness, and diameters of the network harnesses, and make use of topologies that minimize the use of additional hardware and associated mass and power of repeaters, hubs, and switches. This must be accomplished while still affording the ability to support a dynamically configurable network topology for applications such as interfacing with robotic tools, sensors, cameras, or other payloads.

The lack of onsite repair options coupled with long mission durations require the use of network architectures that support fault tolerance and redundancy features for circumnavigating around failed nodes.

Implementation of the node controllers using qualified FPGAs allows space avionics developers to meet the goals of mission EEE parts reliability and radiation environments without the added cost and schedule burden of an ASIC screening, qualification, and radiation test campaign which is becoming increasingly more expensive for GEO missions.

Finally, all space applications require a ground-based test bed which emulates the hardware and software functions of the flight unit to support testing during development and debugging when the flight hardware is deployed. Technologies that come fully equipped with low cost, low schedule, plug and play test bed solutions and provide a wide suite of system diagnostic features are crucial for both the development and flight phases of the mission.

With all of these considerations in mind, EtherCAT proves to be an ideal choice for the next generation space avionics communication technologies for deterministic motion control and sensor interface applications.

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