Industrial Robot Interconnection Concept based on Standard Network Technology

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Abstract—**Based on different enterprise sizes and certain economic regulatory environments for the use of industrial automation solutions, their scalability prerequisite is looming up large. Particularly in robotics automation business, industrial solutions are required, which – with a preceding increase of the number of robots in a factory – do not demand a paradigm change of established solutions or rather already implemented concepts for the same kind of problem scenarios. Additionally, the concept of manufacturing execution systems has to be taken into account since it provides closeness to the automation processes as well as offering the possibility to use the robots as a central real-time data gateway for process data.**

The introduced concept called RoboticsNET, follows the manufacturing execution system philosophy and solves the above mentioned circumstances for networked robots by introducing a highly scalable robot interconnection design based on a fully switched network layout. An increasing number of robots within the robot network do not affect the corresponding technical parameters respectively the principal system behaviour. This paper describes the RoboticsNET fundamental interconnection concept with the focus on scalability regarding rising robot counts in the network in coherence with the orientation towards manufacturing execution systems.

Index Terms—**Industrial software standards, open robot interface design, robot real-time interconnection, scalable network concept.**

I. Introduction

Modern industrial robot systems are a major part of flexible manufacturing and production environments. Due to the ability of reprogramming and automatic changeable end-effectors, robot systems provide an immense increase of flexibility in such environments. Automation systems running industrial robots are very efficient and their designs cover a very large spectrum of manufacturing parts or production applicability. Not just production cycle time, even the time to place the product on the market is drastically reduced. For that case, the time to respond to customer demand is very short. These benefits of automation systems implementing industrial robots encouraged the different manufactures to produce more types and kinds of industrial robots ever. Nowadays, a considerable number of different kinds of industrial robots with different communication interfaces as well as different application software running on them can be found on the market. However, companies usually buy robots from different robot vendors for their particular needs and place them all in the same manufacturing facility arranging automation systems.

Networked robots are still a niche in automation solutions. Taking a closer look to installations already set up, results in finding mainly proprietary solutions without a uniform continuity. RoboticsNET – certain aspects of it are described in this paper – is one of the first approaches to build up a uniform communication infrastructure for industrial robots.

II. Aspects of MES

The idea of manufacturing execution systems (MES) has been developed in the middle of the ninety-nineties with the background, that since the rising complexity in manufacturing, a holistic view of production and service facilities like quality, material tracking, state acquisition, detailed planning etc. is almost impossible. In order to guarantee a rising performance, the expectations for MES are quite high. To deal with all aspects in this context there are several topics – like SIX Sigma, Total Quality Management (TQM), optimized material valuation or production planning and control – available for the practitioner [1].

Nowadays a superior product quality is a matter of course for the customer. For that reason and to differentiate against competing companies added value has to be offered. This means that, besides of competing strategy, unique selling points (USP) are required. Such USP could be for example very short delivery times, high flexibility, a broad proliferation of variants, adherence to delivery dates, shorter product life cycles and so forth. These are properties which can only be created by the processes and not by the production itself.

Today's customers want products tailored to their demands. This circumstance enforces an additional product variety on the manufacturer side, which leads to a massive cost increase. For balancing the additional costs, the manufacturer tries to e.g. reconsider the manufacturing depth, to use more standard components or to obtain appropriate components on the global world market. In particular the manufacturer has to be aware of the aspects of integration and networking, dynamic circumstances respectively criteria's and individualization. But these three aspects have significant effects to manufacturing companies and require highest possible flexibility from the manufacturer.

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From all mentioned effects and their in-house needs – requirements for internal order processing and external market dynamic as well as changeableness, stronger external networking, cooperation with more or permanent new partnerships as well as faster structural and technological adaptation – every level of a manufacturing enterprise is differentially affected. But the effects are capable of being influenced massively by faster reaction within and between the different manufacturing levels. Thus the processes have to become more transparent. To reach this goal of more transparency, it is necessary to adapt or replace ineffectual or antiquated industrial business processes. As the case may be, new processes have to be introduced to reach the desired transparency. Because of this approach, communication constraints between enterprise level, manufacturing management and production level can be avoided. Thus leading to a faster and more effective information flow which results in better reactivity.

In order that the already prefaced measures take effect for the target of increasing transparency, reactivity and economic efficiency, breaking new ground is required as well as accepting added efforts. The achievement of objectives can strongly be supported by the tool MES. This term stands for a technology which development in Europe comes more or less from the classic disciplines like machine and production data acquisition, personal data collection, manufacturing detailed planning and quality assurance. The intent of MES is that value creation processes become more transparent and resulting in horizontal and vertical direction control loops. Thereby the control loops cycle times are oriented according to the respective tasks. That means e.g. for manufacturing just a multiple of minutes and not like in a common enterprise resource planning (ERP) system in a shift or even a day. The closer the production finish date of an order come into reach the more difficult it becomes for the responsible persons to make the right decisions since these decisions are dependent from the available and disposable resources. From this it follows that the field of activity lies not in the area of planning but in the area of short-term production control. Since that area is the field of duty, now the responsibility shifts from the ERP level to the MES level [2].

It is obvious that decision making on MES level requires real time data from the manufacturing processes respectively the automation solutions and appropriate software tools. The short given description of some major aspects of MES should describe the context where the presented research was done. A prerequisite for implementing MES in robot automation solutions is therefore to get the real time process data from the robots which require real time communication. The given solution in the following sections can be seen as one of the first approaches to realize a uniform communication scenario enabling MES orientation for industrial robots.

III. Concept Base Design

For the analysis and design of an open, extensible and scalable structural design, which fulfils the up to date requirements of robot technology on state of current IT technology, the prerequisite of continuity is mandatory. In other words this condition requires the patency from connecting the sensor actor level to robot controllers as far as running up to the office and ERP level which finally leads to the design of the concept containing the following main components:

- Central server
  a host computer in the role of a central server for database & web. The host collects and saves data from the various data collectors and enables client web access to robots.
- Data collector server
  a data collector server is a server computer which on the one side communicates with the robot controllers on the network and on the other side with the central server hosting the database and web services. The introduction of this concept is mandatory to guarantee the scalability of the system for large installations. For instance in large installations the data collector server buffers write demands to the SQL database on the central server during high load phases (several robot controllers write simultaneously). Events will not be buffered but passed through directly as well as the messages from the central server via data collector servers to robot controllers.
- Robot controller
  one or more robot controllers with standard Ethernet network access and the availability of an appropriate application programming interface [3].
- Network
  a network according to the characteristics described in the following sections.
- Communication protocol
  a TCP/IP based communication protocol supporting the robot controller application programming interface.
- Client
  local or remote PC's which are able to access the central server respectively the hosted applications by an internet browser [4].

On account of the RoboticsNET scalability characteristic described in this paper, the information flow from or rather to the robot controllers can be distributed over several data collector servers. The implementation of the data collector server's interrogator can either be based on polling or an event driven mechanism. Spontaneous, asynchronous messages are always event driven. Due to performance reasons regarding load balancing, the data collector server implements an in-memory buffer, which also serves short, temporary connection interrupts. Being offline for a while leads to data loss. For a warm restart without data loss respectively error recovery the possibility of using a message queuing server exists to ensure data integrity. However, this leads to a performance decrease which is in contrast to the concept's real time requirements.

IV. Real Time Considerations

One of the major constraints for the network design of RoboticsNET was the usage of standard hard- and software from the office world with all its advantages and disadvantages. Since the aimed application scenarios the time frames can be significant higher than upper limits for real time control tasks via network (e.g. movement control of a milling cutter in a machining centre or control of drive systems) the determinism of communication becomes more important in comparison to the representative time frame concerning speed. The developed system design within the issue of real time Ethernet difficulty can be described as follows.

The tough requirement for real time properties in wide areas of automation was always the strong argument against the introduction of Ethernet technology with the CSMA/CD access method as a base communication system. Ethernet uses a user shared media realizing the network functionality. Every participant can send a network package after checking the media for being unused.

However, simultaneous transmitting and the finite velocity of propagation may lead to collisions on the media. CSMA/CD takes care of such collisions and retransmits the packages so that no package will be lost and finally reaches the target participant. The thereby elapsed time however, can not be predefined since the MAC access method is a non deterministic method, which excludes the usage in the area of real time systems.

The strong development progress in network switching technology conversely enables the avoidance of the described difficulty if used properly. Once a package arrives at the switch from a network segment, a check for the target segment is done. The forwarding just takes place if the target segment is being unused, which means, that currently no other package is on that segment. Exists already a package on the segment, the switch latches the package and transmits it immediately after the target segment gets free again. Therefore a switch applies a separate channel between the respective source and target port. But using the switching technology for the realization of real time operation requires two additional strong boundary conditions:

- maximum micro segmentation of the switched network (exactly one participant per port)
- full duplex operation of all used components

Considering these two conditions without exceptions results in avoiding collisions and blanks the stochastic access method. Further the full bandwidth of the network is available for every participant. In order that the periods for package transmission can be appointed with declaration of an upper limit which results in determinism (non-blocking design with uncritical total delay). Of course, the backplane of the used switches must have an adequate bandwidth. For the aspired application scenarios a lowest switching capacity of 12 GBit/s and a forwarding rate of 9 Mpps are required (twenty-four 100 MBit/two 1 GBit Ports).

V. Scalable Interconnection Concept

Based on different enterprise sizes and a certain economic regulatory environment for the use of industrial automation solutions, their scalability is looming up large. Particularly in robotics automation business, solutions are required, which – with a preceding increase of the number of robots in a factory – do not demand a paradigm change of established solutions or rather implemented concepts for the same kind of problem scenarios. The fundamental interconnection concept has therefore be focused on scalability regarding rising robot counts in the network and having in mind the use of it within a manufacturing execution system environment [5].

On the base of a fully switched network RoboticsNET provides a reasonable delimitation founded on current available standard hard- and software for the usage in small, medium and large installations. The empirical tests have yielded in describing three classes of installations. In small installations up to eight robots, the central server and the data collector server can be hosted on the same machine without performance issues. Above that, a separation to different host computers is required. Up to 24 controllers can then be connected to a data collector server which corresponds to a medium installation. In large installations additional robot controllers can be supplied by adding data collector server's step by step (max. 24 controllers per data collector). The central server machine has to be designed for high availability. Figure 1 shows the scalable layout for e.g. 216 robot controllers.

Robot controllers are connected with 100 MBit full duplex per port. The connection of the data collector server as well as the connection up to the GBit backbone (through which the central server is connected) takes place via the two GBit uplink ports. For that reason a flat network structure is the result which concurrently solves the 'many-to-one-traffic' problem too. This difficulty arises by maximum micro segmentation of a switched network whether a lot of participants access one micro segment with high frequency (e.g. typical server operation). That micro segment represents subsequently a bottleneck within the communication system. By usage of uplinks with a higher bandwidth the problem is bypassed. If there are no such special ports on a switch, usually the possibility for bundling of ports (link-aggregation) to one or more uplinks with higher bandwidth exists. To reach more performance on higher protocol levels, it is recommended to use packet oriented protocols (e.g. UDP prior to TCP).

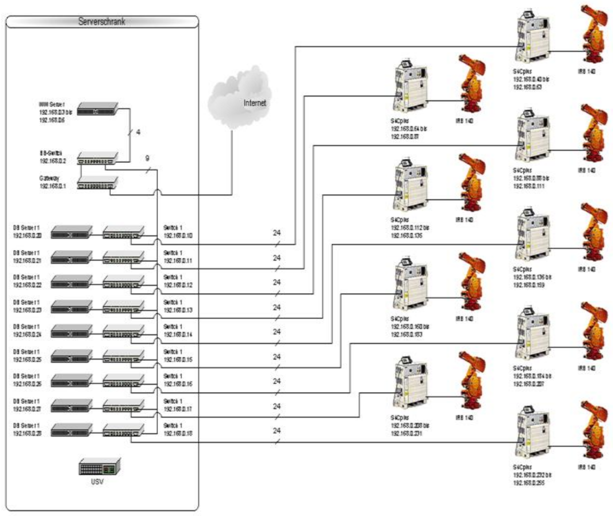

Fig. 1: Overall scalability outline for 216 robot controllers

VI. Outline of a Prototype Application

In Fig. 2 (below) the current status of a prototype application in plastics industry using RoboticsNET architecture is shown. The scenario contains eight industrial robots with their belonging moulding machines, the terminal stations for quality control as well as the teach pendant units (PHG) of the robots for entering certain production data (mainly the order reference number). The recorded data of the robots, the moulding machines and the terminals will be centralized collected within a SQL database, which means, that they are therefore available for reporting. Furthermore, real time data access to the network devices is possible within the network. The design follows the principles of RoboticsNET explained in the previous sections.

Automatic data collection takes place via the robot controllers as central data collecting gateways using the particular controller's main task and background task. Within the main task are the routines for the manipulator movement. The task is typically running in a cycle. The main program is now written in a way, that between the different procedures all interesting data will be buffered in certain container variables. At the end of each cycle, all such datasets will be written to the SQL database. For real time access, certain predefined or controller variables can be set, which are then accessible via network.

The background task realizes the interface between the robot and the moulding machine respectively in consecution between the moulding machine and the SQL database. The communication between the robot and the moulding machine is realized with interrupts and I/O signals. A unique initialization of the interrupt takes place at program start-up, which initializes certain variables. As signals from the moulding machines are queued, the interrupt assigns the signals to their appropriate variables. Completed with other necessary data from the process (coming from the main task, e.g. order reference number), the data will be written into the remote database. Here in the background task is fully independent from the main task, which means that different tables in the database can be filled autonomously.

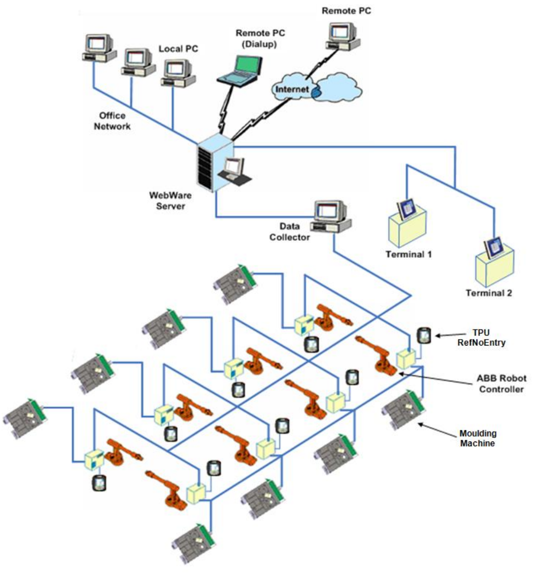

Fig. 2: Application prototype topology (plastics industry)

Additionally to automatic data collecting a manual one takes place coming from three stations: the teach pendant unit of the robot (mainly for entering the production order reference number), the quality assurance application running on terminal computers (TQM system) and the SQL database master data management application running on common computer clients (directly connected to the SQL database via ODBC standard connection).

VII. Conclusion and Further Research

For the RoboticsNET concept an increasing number of robots within the robot network does not affect the corresponding technical parameters or rather the principal system behaviour. The real time behaviour on the level of the network is created by the stringent use of a fully switched infrastructure with certain additional conditions avoiding collisions on the Ethernet which results in determinism. For guaranteeing the real time data accessibility and the scalability of the system, network micro segments are built with connections to data collector servers. Data collector servers are common server machines with an in-memory database, parameterized schedulers and software agents which are realizing the connection of the various robot controllers to a central host system with a persistent database. The aimed continuity of real time requirements within the RoboticsNET concept considering a deterministic sense was realized from hardware side up to network level. Currently the software infrastructure uses legacy protocols and parameterized standard operating systems to already enable applications on that platform which lack required real time considerations and determinism. That case has to be improved within further research. One promisingly approach is in the direction of service oriented architectures (SOA) regarding software infrastructures. The point of central interest in SOA philosophy is platform independent interoperability. SOA conform implementations just should apply the process logic of the correlative applications. The manner how data can be exchanged, whether data transmission is encrypted or not and with which protocols software components communicate, adequate real time and quality of service requirements as well as further infrastructural problems, should be solved just by parameterization and configuration.

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