INFORMATION ARCHITECTURE FOR RECONFIGURABLE PRODUCTION SYSTEMS

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Abstract: *The trend towards greater flexibility in production system has impact on industrial communication. One of the challenges for future research and development is to simplify the connectivity between automation equipment (e.g. robot and machine tool). Still automation equipment is connected via digital inputs and outputs or fieldbus systems and configuration can only be done at considerable expense. To meet the requirements for higher flexibility in robotized manufacturing cells an information and communication architecture, in which new components (e.g. NC controls) can easily be integrated, is required. In this paper we present a cell cache based on blackboard communication architecture that allows adding or removing hard and software-components without reinventing the information architecture. For implementation of the developed approach a robotized manufacturing cell consisting of two machine tools and a robot was assembled.*

Key words: *robotized manufacturing cell, blackboard, XML, robot, machine tool*

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1. Introduction

A reconfigurable manufacturing system (RMS) can be defined as a system formed by the addition of basic process modules (hardware and software), which can be replaced, changed or reconfigured fast and easily (Trullas-Ledesma & Ribas-Xirgo, 2009). From the attitude of technical feasibility many production processes could be automated. The deployment of a robotized manufacturing cell is often not cost-effective due to small and varying batch sizes and the systems' lack of adaptability. This fact presents an economical barrier for automating different manufacturing processes especially for SMEs or non-traditional industries (Vidal et al., 2011). Instead of adapting the production system to a new product by redesigning the entire cell, the approach for robotized manufacturing cells should be different. We should be able to add or remove single components to reach the desired degree of automation. The flexibility of RMS not only refers to the capability of producing a variety of products, but also to the capability of reconfiguring the system itself (Trullas-Ledesma & Ribas-Xirgo, 2009).

Achieving the postulated reconfigurable manufacturing systems (e.g. robotized manufacturing cell) requires an appreciable amount of research in different areas. One field is concerned with the information exchange between components of the cell and the control system. Creating a robotized manufacturing cell which can serve as an experimental rig in an academic environment is essential for testing different scenarios and approaches.

This document addresses the design of information exchange architecture in an academic environment for the purpose of scientific experimentation with a reconfigurable manufacturing system.

2. Communication Industrial Robot – Machine Tool

The need for developing flexible production cells requires appropriate communication between production resources. There are different logical concepts and physical implementations for information exchange between robots, NC-machines and other components.

A state of the art system is based on communication technologies which are available on the market. The implemented solution corresponds to the intersecting set of interfaces that are available on the used components. The frequent consequence of this fact is a severe specialization of the communication architecture to the present job definition. Often the information flow is realized directly on a hardware level with dedicated I/O (input/output) ports where the typical NC machine tool has limited options (Solvang et al., 2008).

VDMA 34180 provides two different communication architectures for robotized manufacturing cells (RMC).

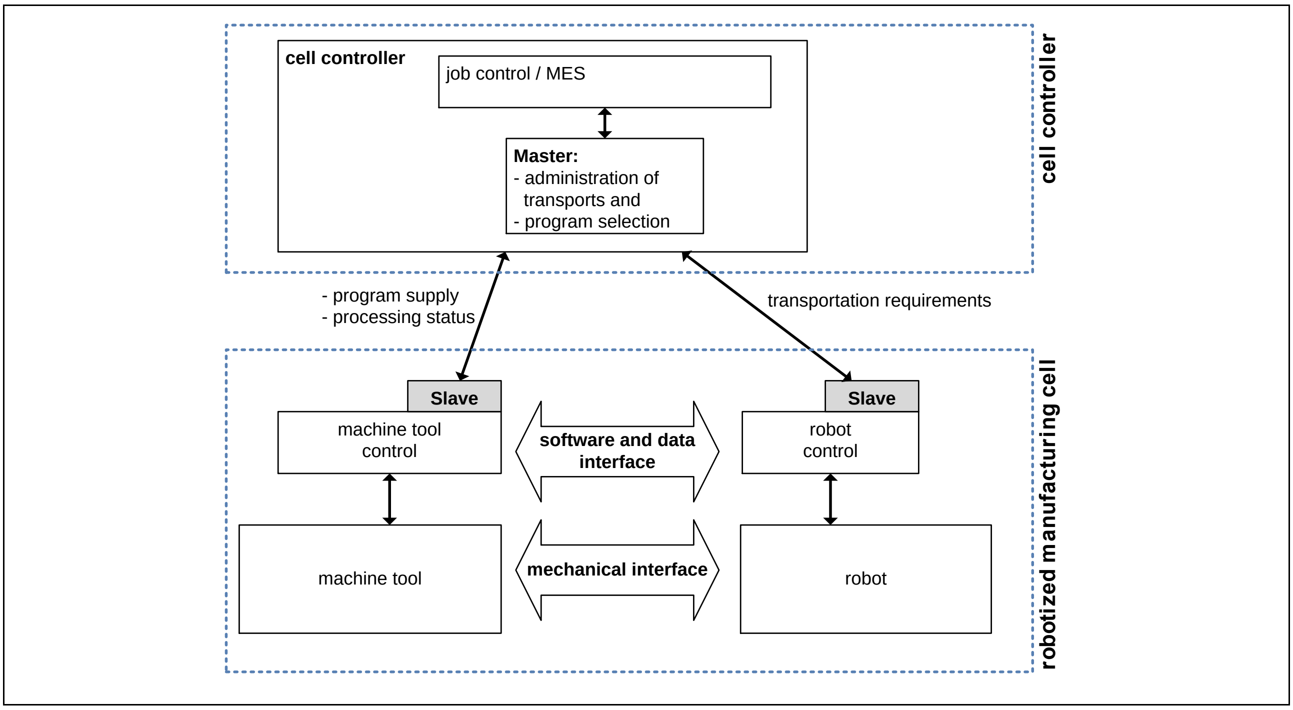

Fig. 1. Architecture of a robotized manufacturing cell with cell controller (Verband Deutscher Maschinen und Anlagenbau e.V, 2011)

Figure 1 shows a possible scenario for the control of a robotized manufacturing cell proposed by VDMA 34180. The interface between cell controller and machine tool is used for program supply and processing state acquisition, the interface between cell controller and robot control for transmission of transport requirements. The orchestration of the activities of machine tool and robot, necessary for the execution of basic operations such as “load part” is accomplished by the machine control and the robot control using a separate interface between them.

Another approach is the direct communication between machine tool and handling device (see fig 2). One of them assumes the orchestration of the RMC and is the master. This approach is no longer sufficient for flexible manufacturing if the complexity of the manufacturing system is increasing. In this case using a cell controller which operates as master is preferable. All connected cell components (e.g. robot, machine tool) have to be considered as slaves (see figure 1).

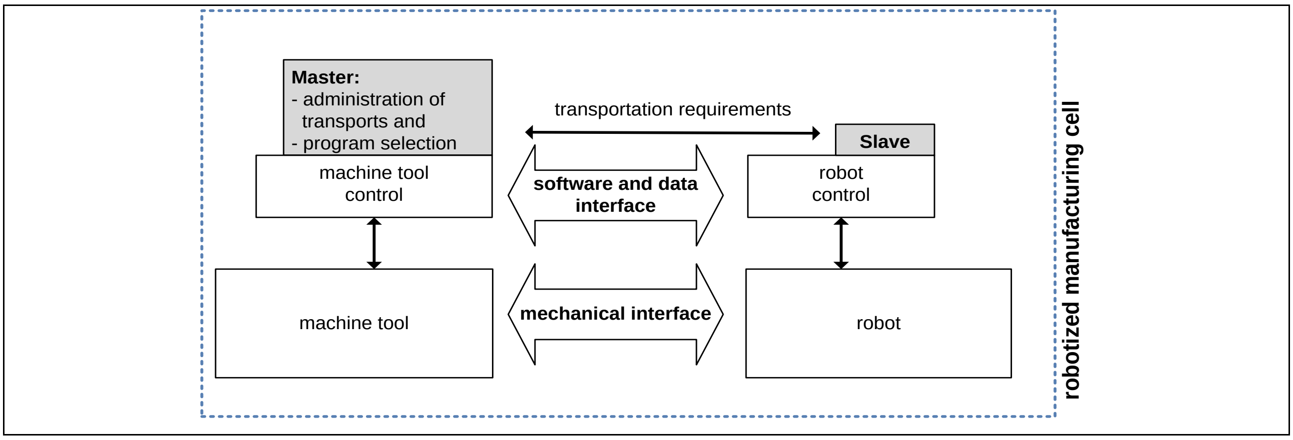

Fig. 2. Architecture of a robotized manufacturing cell with machine tool as master (Verband Deutscher Maschinen und Anlagenbau e.V, 2011)

2.1 DI/DO

In most installations the integration of automation components (e.g. robots, work piece carriers) with machine tools is still established via digital inputs and outputs (DI/DO) of the programmable logic controllers (PLC). This leads to limited flexibility and restricted adaptability. Standards have been introduced in order to reduce configuration effort. An example is the “Euromap”-Project 71 (EUROMAP, 2009) where the connection between injection moulding machines and mould changing devices is defined and standardized. With the VDMA 34180 - data interface for automated manufacturing systems specification, published in 2011 (Verband Deutscher Maschinen und Anlagenbau e.V, 2011), another attempt was made to define the communication between cell components. VDMA 34180 is primarily concerned with the automated work-piece handling for machine tools with industrial robots (machine tending), but still uses I/Os for information transfer.

Communication over I/Os presented in VDMA 34180 is not flexible enough for being used in reconfigurable RMCs. This results from configuration on the hardware level when using DI/DO.

2.2 Fieldbus Systems

Fieldbus is a digital bi-directional serial-bus communications network for real time distributed control. Fieldbus is supposed to link different instruments, controllers, and final control elements (Mahalik, 2003).

Despite the standardization of fieldbus systems with the ICE 61158 there exist several fieldbus standards e.g. CAN, ProfiBUS, EtherCAT. Each manufacturer of robots or machine tools provides different fieldbus standards and a connection between robot and machine tool can’t be guaranteed. For connecting components with different fieldbus systems a converter is needed and has to be configured. Therefore the effort for establishing a connection between the components is increasing.

2.3 Ethernet Based

Pires et al. shows three different types of communication for robots to interact with a PC or other components (Pires et al., 2006).

- RPC (Remote Procedure Calls)
- TCP/IP Socket communication
- OPC

These different types are also useable for NC-machine tools.

There are different manufacturer-specific communication protocols which are based on Remote Procedure Calls. A good example is the Siemens “RPC SINUMERIK”. The RPC SINUMERIK interface allows remote control of NC machines by a PC and has been implemented in an appreciable number of flexible manufacturing systems.

Robot manufacturers also provide different interfaces based on RPC. Formerly ABB used Robot Application Protocol (Cederberg et al., 2002) for communication with the robot controller.

TCP/IP sockets are a platform independent basis technology for information exchange over Ethernet. ABB provides a PC Software Development Kit which is a tool for programmers to develop customized operator interfaces for the IRC5 robot controller. The PC SDK uses an internal Controller API based on COM technology to communicate with the controller. This API uses sockets and the local TCP/IP stack (ABB, 2012).

3. Motivation

Making the assembly and configuration on the information layer (Selig, 2011) of a manufacturing cell as easy as possible, is the ambition of this research. Figure 3 shows a comparison between the state of the art communication architecture in a robotized manufacturing cell and the desired architecture for a reconfigurable manufacturing system.

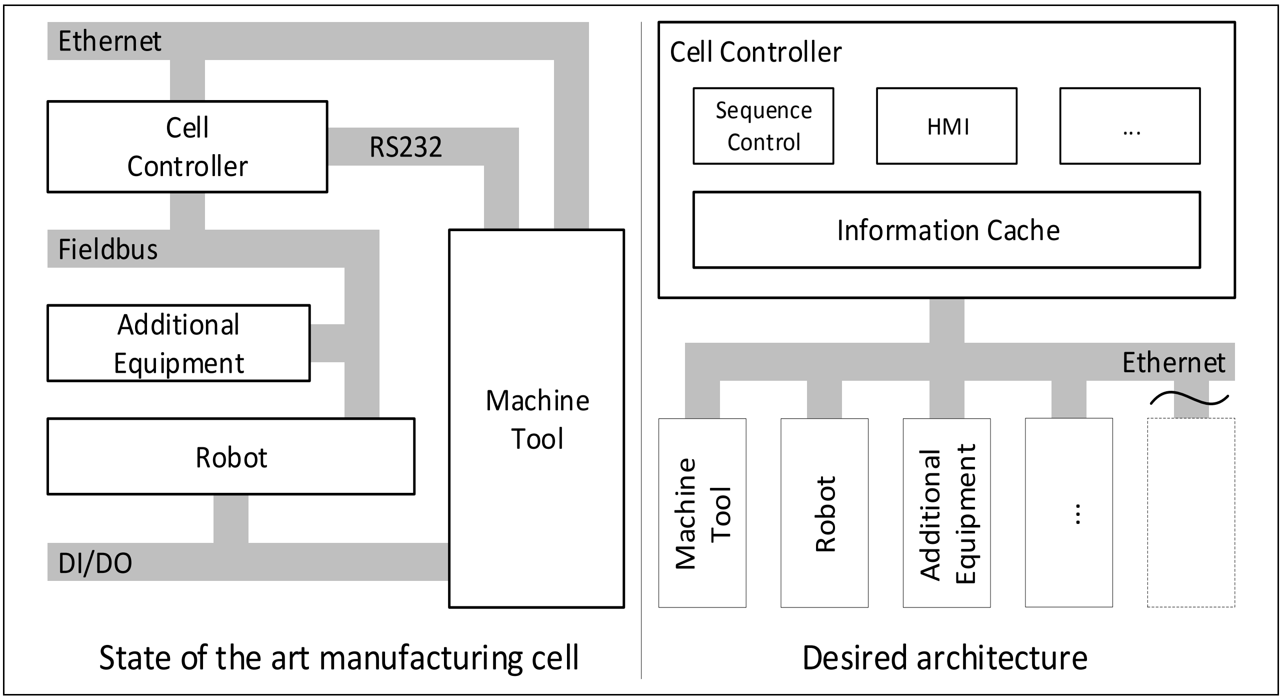

Fig. 3. Comparison of cell architectures

The reduction of complexity, regarding the topology of the communication system and the used hardware, results in lower configuration efforts. This layout should be beneficial for exchanging hardware components of the manufacturing cell.

Simulating a manufacturing system in an academic environment is necessary for research and development. Especially universities are troubled with the associated expense. Finding a trade-off between modelling the reality and keeping the test rig as simple as possible is desirable.

Therefor the IFT uses special training machine tools from EMCO which have the same functions like full-scale machines but are cheaper, lighter and need less space in the laboratory.

R&D projects have durations over years and are simultaneously developed from different individuals. Therefor a platform is needed which offers centralized information storage. Each newly added component should be able to access the data of the entire system as easy as possible.

4. Conceptual Basis

As shown in chapter 2, communication between components of a robotized manufacturing cell can be based on various approaches. The IFT (Institute for Production Engineering and Laser Technology – Vienna University of Technology) implemented a communication concept based on blackboard architecture which shall be used to develop plug & produce ability for robotized manufacturing cell components in the near future.

4.1 Blackboard Systems

Blackboard systems (BBS) were first developed in the 1970s to solve complex signal-interpretation problems in systems such as Hearsay-II.

Since the days of those early blackboard-system applications, the blackboard approach has been viewed as an ideal candidate for tackling difficult, ill-structured problems in a wide range of application areas.

An application in which different knowledge sources update a common information cache, called the "blackboard", is entitled as blackboard system (Corkill, 2003).

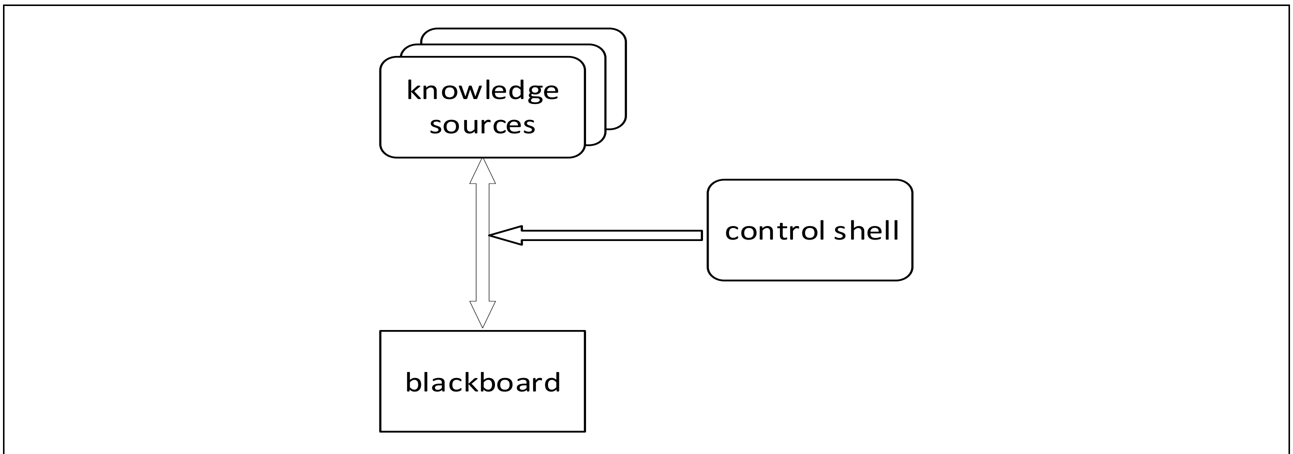

Fig. 4. Blackboard System Components (Corkill, 2003)

H.P. Nii defines a Blackboard System (BBS) consisting of three main components (Nii, 1986) shown in figure 4.

- Knowledge sources (KSs)
- A blackboard (BB)
- A control component

Corkill defines knowledge sources as independent computational modules that together contain the whole expertise needed for problem solving. Knowledge sources do not interact directly with another or know other KSs in the system (Corkill, 2003).

Each specialist (KS) watches the blackboard, looking for relevant information. In case of an event which causes a relevant change in the blackboard, the specialist springs into action. Blackboard events are adding some new information to the blackboard, changing existing information, or removing existing information (Corkill, 1991).

Knowledge sources in blackboard systems are triggered to external events and changes on the blackboard. Each knowledge source informs the blackboard system which events are necessary for them. The blackboard system records this information and directly informs the knowledge source whenever that kind of event occurs. So the knowledge sources do not have to scan the blackboard all the time (Corkill, 1991).

The blackboard is a global data structure used to organize the system state data and to handle communications between the knowledge sources. The objects that are placed on the blackboard could be input data, partial results, hypotheses, alternatives and the final solution (Pang, 1988).

The control component makes runtime decisions about the course of problem solving and the expenditure of problem-solving resources. The control component is separate from the individual knowledge sources (Corkill, 2003).

4.2 Master – Worker Pattern (MW)

Sottile et al defines a master as a single thread that manages a set of tasks and coordinates the execution of the worker. Workers are one or more threads which compute the task. They take one task from the master, run it and return it to the master to get the next one (Sottile et al., 2011). A typical use case is shown in figure 9.

Master - worker pattern is also one of the simplest communication principles. This principle consists of one master and one or more workers (slaves). The master is the centralized control of the network. The other devices are slaves and communicate when permitted or requested and only with the master (Strauss, 2003).

4.3 Selected Approach

Coming from blackboard systems our communication approach uses centralized global data storage. In contrast to blackboard communication in artificial intelligence the knowledge sources are not intelligent instances. They only update their state on the blackboard and wait for commands which are published on the blackboard. There is no explicit control shell like in true blackboard systems. The file system of the host PC performs some rudimentary functions of the control shell using read- and write-locks.

For sequence control a specialized application is put in place. This single program is responsible for organizing the entire system. So there is one master which distributes the required jobs for completing the production process. This is done via commands placed on the blackboard and executed by the different components (slaves). This control procedure embodies a master - worker pattern.

The concept shown in figure 5 represents the actual state of our implementation and will be used as the initial point for further research projects.

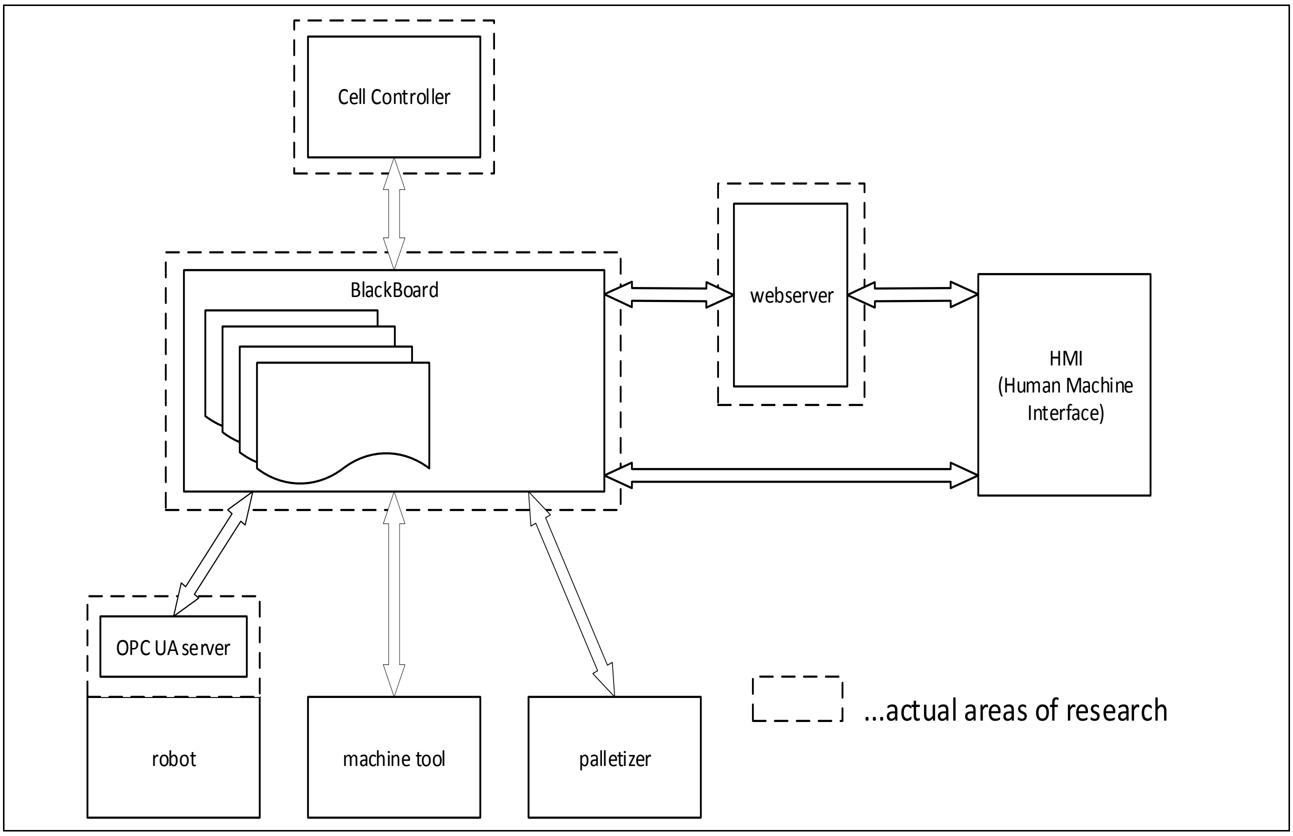

Fig. 5. Communication concept of a RMC

5. Experimental Implementation

In the course of a diploma thesis a robotized manufacturing cell (RMC), consisting of two machine tools (turning and milling machine) and a robot was fully assembled and put into operation. The cell design is modular and therefore allows flexible assembly with respect to the arrangement of the cell modules.

For organizing the cell processes the developed communication concept based on blackboard architecture for data storage and master-worker pattern was implemented. With this concept it should be possible to add or replace software and hardware components of the robotized manufacturing cell without reinventing the information architecture.

Producing a slot car rim has served as test case for the robotized manufacturing cell. Manufacturing this work piece required turning, milling and some handling operations. This resulted in a complex scenario where the functionality of the control concept could be tested.

Figure 6 shows the final implementation of the communication concept presented in the last chapter. As platform for HMI, sequence control and the blackboard, a standard PC is used (cell controller).

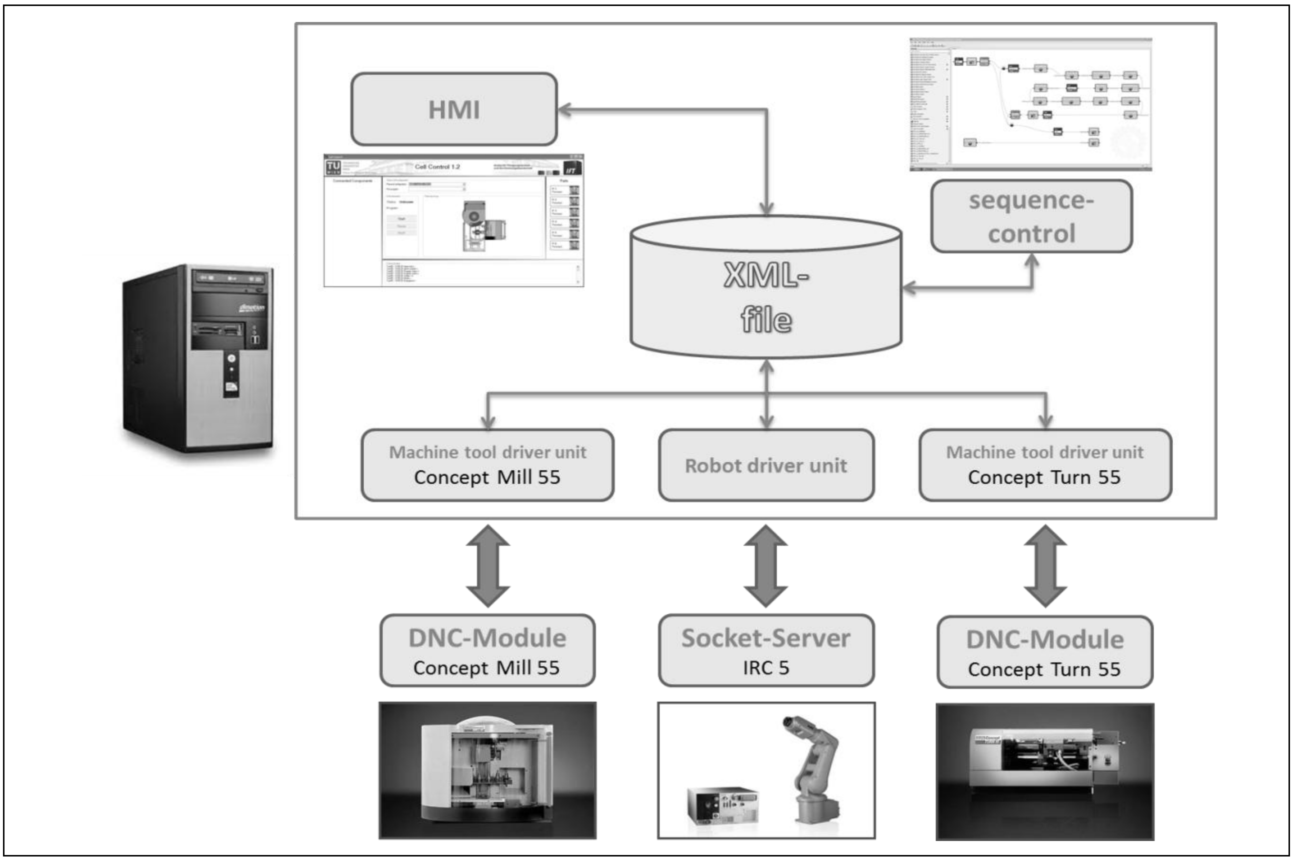

Fig. 6. Communication architecture of a RMC (Pauker and Kühlmayer, 2012)

5.1 Knowledge Sources

Based on blackboard architecture the robotized manufacturing cell has several knowledge sources. Our system has five knowledge sources:

- The turning machine
- The milling machine
- The robot
- The HMI
- The sequence control

Each knowledge source has an Ethernet based communication interface, for interaction with the blackboard. Exchanging data between the EMCO machine tools and the blackboard the EMCO DNC (Direct Numerical Control) interface is used. This is a manufacturer specific communication protocol. EMCO DNC creates a connection between the cell controller and the control computer of the NC-machine tool. All data e.g. NC-programs, tool data, etc. can be transmitted.

For communication with the ABB IRB 120 robot a communication module was developed. This module uses network sockets for communication and runs on the robot controller. The communication module uses an independent task on the robot controller. This design enables the robot controller to respond on any requests during movement.

The robot communication module sends all status information as a single string message to a driver application on the cell controller. This program updates the blackboard. For better understanding figure 7 shows an example message send from the robot to the driver.

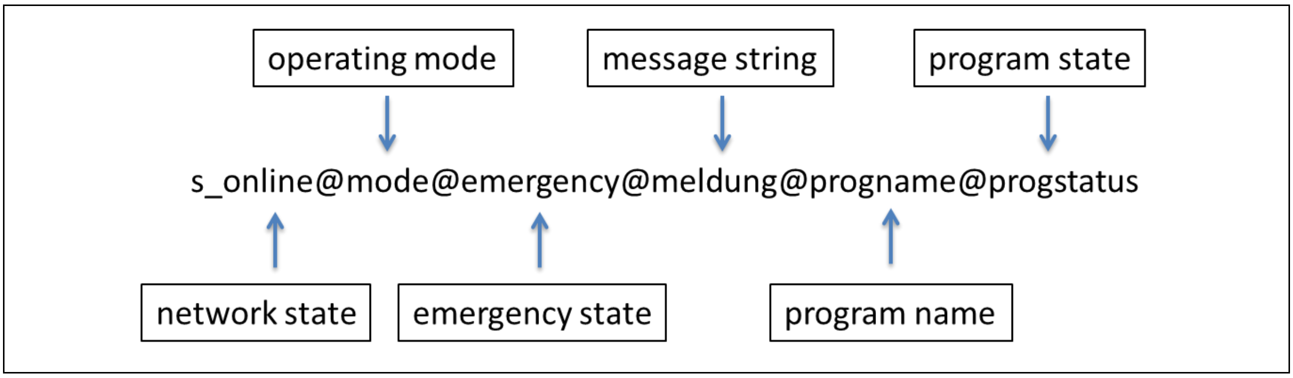

Fig. 7. Communication protocol ABB IRB 120 (Pauker & Kühlmayer, 2012)

The message string sent from the robot to the cell controller holds all necessary information separated by the "@"-separator. The blackboard is informed of the:

- actual operation mode (if the robot is in automatic mode, ready for work or manual mode)
- actual RAPID-program (ABB, 2004) running
- program state (if the robot is moving or ready for the next command)

These are just some examples and the full communication protocol is documented in (Pauker and Kühlmayer, 2012).

5.2 Blackboard

An XML-file contains the blackboard data structure for storing information. The XML-file is a global database where the structured information of all resources is stored. XML is widely used for data exchange and storage because the code is human and machine-readable. The neat thing of XML is that the document itself describes the structure of data (Bradley, 2002).

A blackboard can be partitioned into an unlimited number of sub- blackboards (planes, panels). That means, a blackboard can be divided into several levels corresponding to different aspects of the solution process. Hence, the objects can be organized hierarchically (Pang, 1988). To realize the idea of planes the XML-file was separated into five files, one for each knowledge source. So the blackboard of the RMC consists of five planes.

In Fig. 8 the blackboard data structure of the milling machine realised as XML-document is shown. The XML structure has one root element (conceptMill55) containing several XML-children. The information is divided into four sub items:

- communication
  (all parameters necessary for communication e.g. IP-address)
- status
- program

- aux
  (all automated machine devices e.g. loading door)


```
- <conceptMill55>
  - <communication>
      <onlineStatus>1</onlineStatus>
      <host>10.0.0.102</host>
      <port>5557</port>
    </communication>
  - <status>
      <mode>A</mode>
      <emergency>0</emergency>
    - <alarm>
        <alarmAktive>0</alarmAktive>
        <alarmCount>0</alarmCount>
        <alarmType>0</alarmType>
        <alarmNumber>0</alarmNumber>
        <alarmText />
      </alarm>
    </status>
  - <program>
      <progName>$WMFELGE\HAUPT</progName>
      <progNameRequest />
      <progStatus>R</progStatus>
      <progStatusRequest />
    </program>
  - <aux>
      <auxStatus>1</auxStatus>
      <auxRequest />
      <blowStatus>0</blowStatus>
      <blowRequest />
      <clampStatus>1</clampStatus>
      <clampRequest />
      <coolStatus>0</coolStatus>
      <coolRequest />
      <doorStatus>1</doorStatus>
      <doorRequest />
      <sleeveStatus>2</sleeveStatus>
      <sleeveRequest />
    </aux>
```


Fig. 8. XML-structure of the milling machine tool (Pauker and Kühlmayer, 2012)

5.3 Sequence Control

Figure 9 shows the interaction between sequence control, blackboard and two knowledge sources. The sequence control puts a request on the blackboard (door_open request). The responsible knowledge source, which scans the blackboard, is now able to react on this instruction. The KS executes the command and provides a confirm notification on the blackboard when the action is accomplished. Now the sequence control has to perform the next step.

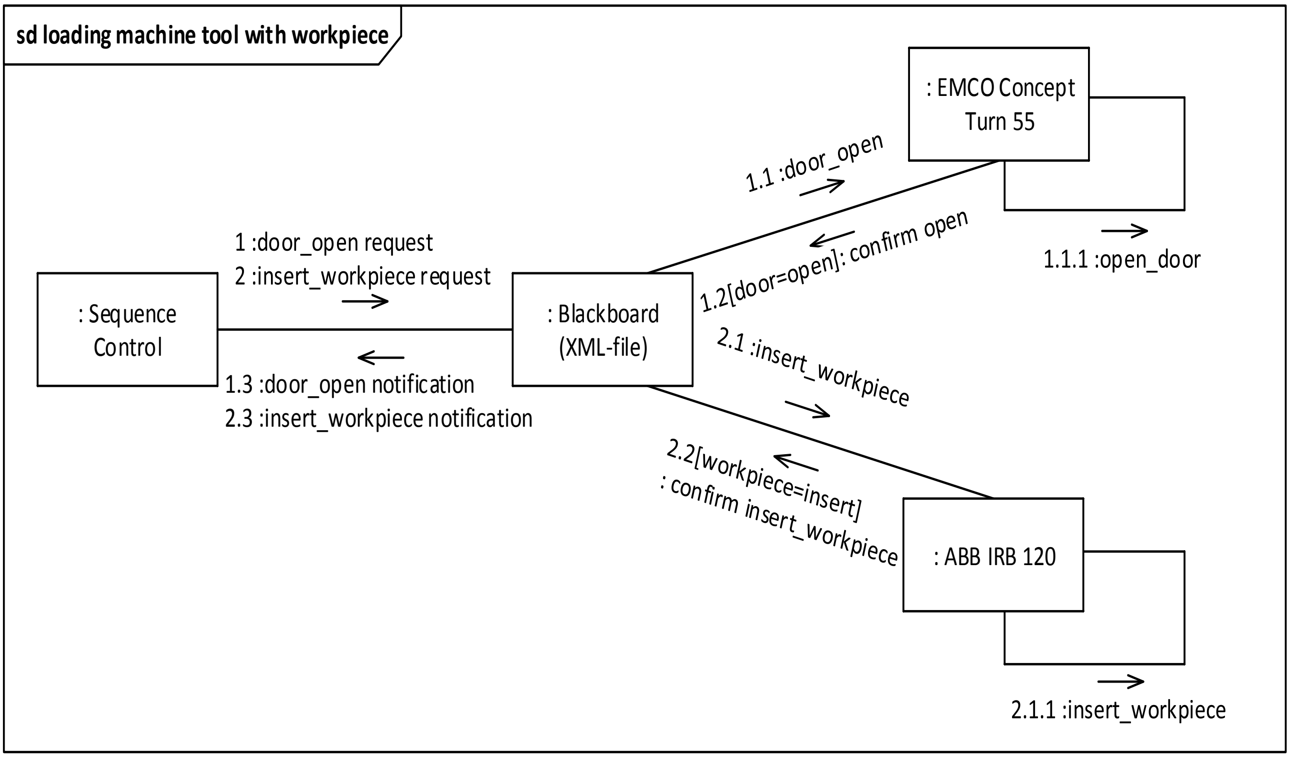

Fig. 9. UML communication diagram of loading a machine tool with the robot

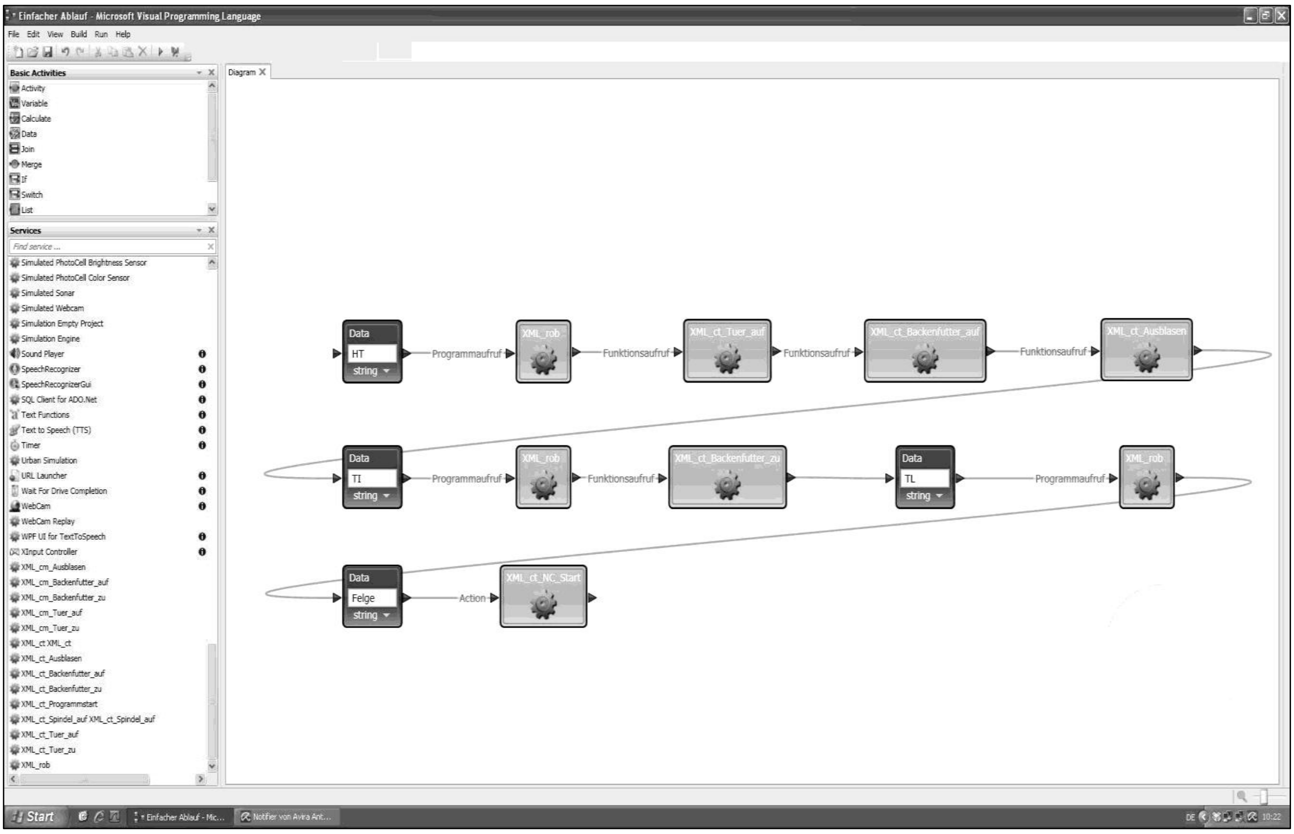

Fig. 10. VPL with drag and drop functionality

The sequence control (SC) is not the control module of the blackboard system. It’s a knowledge source monitoring the changes on the blackboard and managing the workflow in the robotized manufacturing cell.

The sequence control application was realized using Microsoft Robotics Developer Studio. Figure 10 shows a simple sequence programmed with visual programming language which is provided by the used IDE (integrated development environment).

6. Conclusion

This paper shows a basic concept for flexible communication between cell components. The usage of a blackboard as centralized data storage simplifies the communication infrastructure of the robotized manufacturing cell. The used automation components communicate via Ethernet with a cell controller (CC) which coordinates the sequences.

The development of a service based sequence control (SC) using visual programming language was a test run for testing the potential of the communication architecture. Manufacturing the slot car rim with our experimental RMC was a successful test run under realistic conditions. This test shows that the presented architecture is usable for orchestration of a robotized manufacturing cell.

During testing problems with the XML-files occurs, mainly performance issues. Especially for orchestration of a robotized manufacturing cell many knowledge sources are retrieving information from the blackboard. To get the information from an XML-file it must be parsed. The XML parser extracts the information stored in the XML document in order to avoid any of the difficulties that occur when reading and interpreting raw XML data (Ross, 2007). Avoiding inconstancy of the blackboard is only possible using read- and write- locks. This causes longer processing time because one task can block others. These problems cause a rethink of the actual communication architecture. Using a SQLite-database as blackboard is currently discussed.

Another weak point of the presented approach is the socket based communication. In a follow-up project the communication between cell controller and peripheral automation components will be revised to increase the flexibility and adaptability of the RMC. We propose a solution where machine and robot controllers with integrated OPC UA Server technology expose data and function blocks to OPC UA clients whether in the cell controller or the corresponding device controller (machine tool or robot). All automated functions of the devices can be activated through one single interface, which also will be used for data transfer (e.g. NC programs, tool data). Robotized manufacturing cells may incorporate a cell controller, or the functions of the cell controller are accomplished by one of the device controllers (usually the robot controller).

The focus of this project was put on creating an information model and serving a centralized data cache. The blackboard proved as good solution for illustrating the information model. A blackboard is also a good approach to realize an adaptable architecture where new components can be added easily. Currently a webserver is under development, which should be able to provide the information from the blackboard to other devices like smartphones, tablets and of course desktop workstations.

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