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An agile information processing framework for high pressure die casting applications in modern manufacturing systems

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Abstract

Modern production of high pressure die casting parts raise new challenges regarding planning, scheduling and analyzing of the underlying manufacturing process. The smart factory approach and the research and development pursuit of the fourth industrial revolution necessitate the refurbishment and upgrade of already existing manufacturing systems and the introduction of new information and communication technologies (ICT) in automation systems in order to achieve a holistic, company-wide information exchange and a pervasive traceability of product and manufacturing data. According to this approach, previous programmable logical controls (PLC), established business intelligence solutions and existing manufacturing execution systems (MES) with mutually lacking interfaces are integrated into a new ecosystem for planning, executing and analysis applications. Due to the fact that each system persists on its own user interface, the implementation has to be strongly coupled to a user centered design of innovative human machine interfaces, joined into one distributed, networked application.

In this paper, an agile information processing framework for foundry purposes is presented. Every underlying application is accessible via web-based user interfaces providing control of each single system. This leads into a service orientated architecture triggering the individual underlying systems as services, which are connected using web communication technology to exchange data along a shared information model. The data storage is modular to ensure scalability and interoperability with other manufacturing departments. During the actual manufacturing process, different services like inline data mining analysis are deployed and the results are visualized in user demanded dashboards and reports. For new requirements in business intelligence and MES the developed interfaces are provided in a unique library and a content management system. The described architecture enhances the development of new information applications, accelerates the planning and execution process and is completely orientated to the demands of users, as fast planning procedures and analysis driven user interfaces.

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1. Introduction

High class car design requires emission reduction concurrent to low fuel consumption and the increase of driving dynamics [1]. One innovative and expedient approach to reach these objectives is the introduction of lightweight design. Realizing such innovative lightweight concepts like the space frame technology leads to the intensive utilization and application of high pressure die casting (HPDC) parts for structural purposes in car bodywork [2]. The production of these high tech parts requires a high invest on manufacturing means providing stable and controllable process conditions.

To secure these circumstances, it is necessary to monitor every fault during the process, to support the worker with useful information on changing process conditions and to detect possible material flow bottlenecks in advance. Process-accompanying quality measurements has to assure the feedback of information to the central production process and avoid inaccurate machine settings. Therefore, a wide range of information systems has been introduced in the past which led to a heterogeneous and complex system of systems. Especially in research and development plants, like HPDC testing faculties, the high variety of changing projects necessitate a modular and agile architecture of information systems, which

current implemented system does not provide. Accompanying new manufacturing technologies, a high variety and quantity of measurement systems is immutable. In addition to this heterogeneous situation, the “Smart factory” approach [3] as well as the research and development pursuit of the fourth industrial revolution [4] demand for vertical and horizontal integration solutions in information and communication technologies (ICT). Contrary to these requirements, automation and information systems are in general segregated into separate assignments performing encapsulated tasks, which is a stark contrast to the distributed, networked information concept behind smart factories. In result, the information and data flow between these different layers is fixed and often hardcoded by making use of proprietary interfaces and information exchange protocols. This actual static and hierarchical automation model cannot accomplish the mentioned requirements due to the fact, that interoperable interfaces are restricted or encrypted. Furthermore the business model of commercial software avoids downwards compatibility and the independency of the operation system in order to introduce a stringent license sale model.

On top of this, the fast developing progress in information and communication technologies (ICT) and the long term life cycle of production facilities and manufacturing information systems are diverging, so that the incurrence of a technological gap appears inevitable. Therefore agile approaches are needed to solve this discrepancy by including existing information and automation systems into an agile framework, which provides open interfaces and operating system independency as well as downward compatibility. In addition modern information architectures must be easily portable on other manufacturing and production departments within the company.

In this paper the introduction of a distributed, networked information processing framework for high pressure die casting applications is illustrated on the basis of a use case in the Audi testing foundry. In order to meet the mentioned challenges, this paper addresses the following research questions:

- How can the dilemma of horizontal and vertical integration of modern information systems be solved by suitable approaches?
- How can heterogeneous data be transferred into pervasive and traceable information, regarding the high pressure die casting use case?
- How can real time data streams be analyzed with data mining methods and the related results are visualized?

Section 2 gives an overview of technologies and methods suitable to realize an integration of different information systems. The use case of the high pressure die casting manufacturing process from the ICT point of view is specified in section 3. Based on a newly developed agile information system, the central service for real time analysis by means of data mining technologies is discussed in section 4. Section 5 concludes the described approaches and shows future

prospects or manufacturing information applications, due to agile approaches.

Nomenclature

| | |
|--------|--|
| DWH | Data warehouse |
| ERP | Enterprise resource planning |
| HMI | Human machine interface |
| HPDC | High pressure die casting |
| ICT | Information and communication technology |
| IoT | Internet of Things |
| KPI | Key performance indicator |
| MES | Manufacturing execution system |
| MQTT | Message queue telemetry transport |
| OPC-UA | OLE for process control unified architecture |
| PLC | Programmable logic control |
| SCADA | Supervisory control and data acquisition |
| SOA | Service oriented architecture |

2. Related work

Control and data acquisition systems along automated production processes are in general implemented as static and hierarchical structures. One prominent infrastructural architecture is the so called automation pyramid (Fig. 1(a)). The following layers are described as top-down formulation by task and highlight the static dilemma of the standard automation approach.

Enterprise resource planning (ERP) acts as global system for scheduling the distribution of human and material resources as well as storing, purchase and financial controlling system. On the shop floor level manufacturing execution systems (MES) were deployed for planning and controlling production processes directly on machines or production lines. Sensors and actuators within the field level are operated by programmable logic controls (PLC). The human machine interfaces (HMI) are effectuated in the layer of supervisory control and data acquisition (SCADA) on decentralized devices located near to the field level.

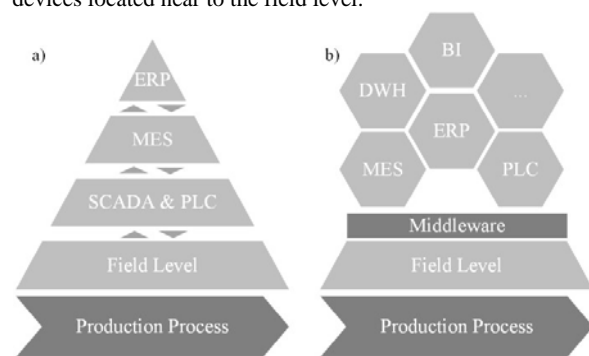


Fig. 1(a) Automation pyramid paradigm; (b) Agile information system approach according to [5]

Each sublayer is used for different planning or controlling tasks. A different approach is presented in Fig. 1(b) [4]. Compared to the automation pyramid, one single information layer connects the different subsystems to the field layer. The information and data flow is managed directly underneath the single applications and systems. For example reporting engines directly access data warehouses (DWH) or MES datasets to create reports or dashboards. The information exchange becomes possible by negotiating between each system on using an extensible information layer as middleware.

Hence, a testing and development department with high variety of measurement systems and sensors needs dynamic solutions. As mentioned before, the life cycle of mechanical facilities, automation systems, and software differ blatantly [5], which results in the necessity to deploy new software solutions, which follow a model driven development procedure and a modularization of each subsystem. The terms of “Industrie 4.0” or “Smart factory” comprise the integration and consolidation of information flow in horizontal direction from ERP to field level and in vertical direction between information devices and machines within the field level [5]. As a consequence, existing communication interfaces between these systems and the encapsulated implementation must be broken up and adapted to the level of a middleware. These adapters respectively integrators are provided by a service repository to secure the interoperability between each application and to enable the communication to each other. The smart factory approach includes the communication between terminal devices among themselves and real-time-compliant software that can be interlinked spontaneously [6]. Therefore existing distributed object architectures (DOA), running on different devices with static interfaces are transformed to service oriented architectures (SOA) [7]. Regarding the holistic approach of scalable, company-wide information systems, SOAs are a proper solution to achieve this goal. Concerning existing DOAs in the financial driven point of view, it has to be balanced out if a reengineering solution or a new implementation is appropriated [8]. A lifetime extension of stock software and modernization to SOA is realized by wrapping these applications into services [9].

In order to use historical data sets in unconsolidated states, the extract transform load (ETL) process according to [10] provides a practical solution. During the extraction, raw data sets from files or different databases are preprocessed and stored into the so-called staging area. Within the staging area data cleansing is processed and the data sets are transformed into information, persisted in a DWH. Based on this DWH, information can be used via object relational mapping (ORM) by service oriented architectures.

An approach for stream processing purposes is the lambda architecture according to [11], where new data are segregated into three different data streaming layers (Fig. 2):

- Batch layer: This layer comprises the master data set and defines views of different entities as well as data mining

analysis models. The training of these models runs batch driven in this layer.

- Speed layer: New data streaming is processed in real time by static views, which were created before or are imported cyclically from the batch layer.
- Serving layer: Queries from services to the agile framework are handled in this layer, who acts as handler for the real-time demands in the speed layer or more complex queries for analysis in the batch layer.

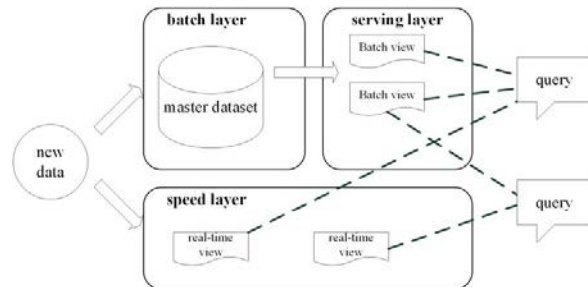


Fig. 2 Stream processing in the lambda architecture

Regarding the field level, the integration of different PLCs, sensors or serial signals into a holistic framework needs an adaptable and flexible standard. Therefore different protocols and standards like OPC-UA and MQTT are upcoming solutions from the level of machine to machine communication (horizontal) up to the communication of World Wide Web (vertical), the so called Internet of Things (IoT).

OPC stands for OLE for process control, where OLE means object linking and embedding. It was developed as standard protocol to provide a communication between PLCs and SCADA. OPC relies on the Microsoft DCOM Standard [13] and is bound to this slow communication protocol. Because of that, OPC unified architecture (UA) was introduced, which uses the TCP/IP protocol for its communication and as a consequence it is independent from the operating system [14]. The major advantage of OPC-UA besides the information flow from sensors into higher systems is the domain driven structure, which describes the setup and sensor configuration of the automated systems. OPC-UA follows an inverted client-server paradigm, i.e. that many servers are deployed directly on the field level and only less clients from upper levels are sending request. Machine to machine communication is implemented by the installation of thin clients on the field level devices [15]. Another protocol for horizontal communication is standardized in the message queue telemetry transport protocol (MQTT). MQTT is easier to implement on fieldbus systems with higher latency in comparison to OPC-UA, which consist a hierarchical structure, albeit several domain specific implementations are distributed [16]. Afterwards in this paper, the usage of OPC-UA is chosen. On wrapping serial signals or PLC interfaces by OPC-UA servers, it makes it possible to connect these data sources directly into an information processing framework.

Generally spoken, OPC-UA implies the functionality to run UA Servers as Services and to define a XML-based Protocol. In conclusion OPC-UA can be used as SOA itself.

Concerning research and development of data analysis in high pressure die casting, first steps were initiated by [17]. Using artificial neural networks, this work aimed on detecting optimized process parameter properties including four central measurement values of temperature of melt, vacuum in the mold, velocity of the piston and the clamping force. Another approach comprises the implementation of a non-generic application showing the capabilities of data mining methods in manufacturing, which resulted in a reduction of production rejects of nearly eighty percent [18]. An actual research project focusses on developing and testing a real time cognitive control system especially for high pressure die casting applications [19].

3. Agile information processing framework for HPDC

3.1. Use case testing foundry

The implementation of our agile information processing system is evaluated by a use case in the production domain of high pressure die casting. Due to the high variety of process parameters, the different communication standards in this manufacturing domain, and the lack of information systems, the use case in HPDC is ideal for refurbishing older PLCs and the deployment of modular ICT. The initial situation is characterized by isolated solutions for information systems with lacking interfaces.

The manufacturing process and the different steps are listed in Fig. 3. The initial step is the melting of lightweight metal, like aluminum. One of the characteristic attributes of liquid aluminum is the high affinity to hydrogen entrainment. To avoid this, the liquid melt is treated by an impeller flushing inert gas into the metal in order to substitute the hydrogen. Otherwise, the major die casting defects, the so-called gas porosity is very probable. Due to the fact that this continuous production process changes to a batch process for producing single parts on the die casting machine, it is necessary to have enough melt as reservoir. Dosing furnaces accomplish this task during the production process. Quality determining analytics like spectral analysis are taken out after each step until the melt reaches the die casting machine. The main production step takes place on the die casting machine and is accompanied by several measurement and automation systems. HPDC is characterized by the injection of liquid nonferrous metals under high pressure into a mold. The injection process is achieved by a piston, pressing the melt by high velocities into the mold, the so-called die during 20 – 50 milliseconds. The main values for accompanying measurement systems during this manufacturing step are different temperatures, pressures, forces and piston velocities. Process-related to HPDC, dispensable areas of the part are removed by trimming and are melted as recycled material in the melting furnace. Rejected parts are detected by optic user

examination and are documented in a quality system. The last three steps of machining, heat treatment and surface finished are performed by second tier partners. The information flow during the external manufacturing processes is transmitted batch wise by reports.

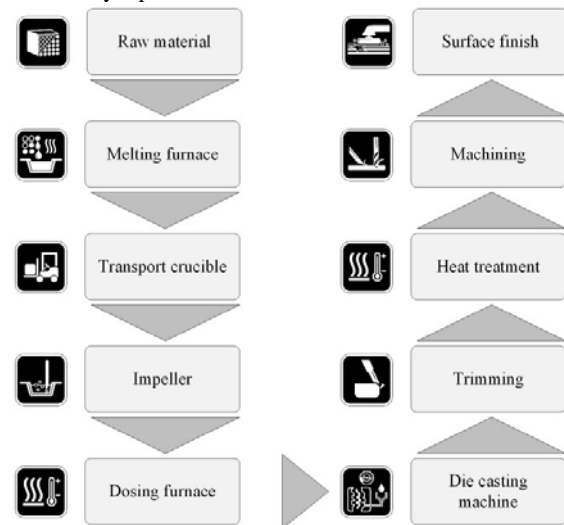


Fig. 3 Production process for high pressure die casting parts

The initial situation for this use case comprised paper based quality acquisition and a high quantity of variant PLC and MES interfaces. In order to solve this challenge the focus lies on the integration of these different interfaces into one service based framework for foundry purposes.

3.2. Information framework

This framework comprises a repository of integrators, which can be used easily for adding new components and devices. This adaptable approach is extended by the implementation of data driven services, e.g. real time data streaming for data mining analyses. A user-centered design aspect quickly solves the demand on new visualization applications by using actual web technologies of HTML5. Thus, different types of reports and dash boards are implemented and provided as libraries. Hereby, the time spent for user interface development cycles could be reduced to a minimum. Besides this agile frontend development, the backend implementation is adapted in the same manor. Existing MES solutions and database systems are not rebuild, they are transferred by wrapping them into a service in the die casting framework. By following this approach, a modular an agile solution for the transformation of elder static systems is implemented. There is no necessity of reengineering or the totally new development of adapted information systems. Consequently, the development of a service oriented architecture is achieved by wrapping old systems into the framework and by creating new applications as services. Regarding communication abilities on field level, like sensors

or different PLCs, the usage of the OPC-UA standard enables a fast integration methodology, linking serial signals via an OPC-UA server on an embedded device into the network. Java based OPC-UA clients are used to communicate with the embedded OPC-UA servers via Ethernet and TCP/IP. Thus, different field level data sources can be easily integrated into the agile information processing framework for HPDC.

As mentioned before, the framework is based on open source code and it was implemented in Java, which guarantees an operating system independent runtime environment. The development and implementation uses the Spring framework, principally out of three main reasons:

- Object relational mapping (ORM): Spring allows an easy integration of ORM frameworks like Hibernate, which enables the ORM functionalities, i.e. elder relational database models can be converted and manipulated in an object oriented language by mapping entities to objects.
- Web functionalities: User interfaces are developed consistently web based for the HPDC requirements. Spring provides therefore the needed Web-Servlet functionalities.
- Test driven development (TDD): In order to ensure a stable, nearly bug-free software, every service is implemented with adapted tests, before delivering the new services in the production runtime environment.

Based on this development environment, new requirements from users in the HPDC foundry can be realized in short term developing cycles. Close to process planning and mechanical engineering, this approach can easily implement requirements of users. For example aggregated data from real time processes like the measurement of temperatures in the melting furnace can be quickly visualized in the control station. Process planning properties like linking alarms and events to maintenance plans or the key performance indicator (KPI) of the overall equipment efficiency (OEE) became possible, without setting up a new bought application. Real-time and aggregated data, as the mentioned temperature and the OEE are handled oriented to the lambda architecture paradigm. It is not necessary to run every data stream on the same service.

Based on the described architecture a wide range of services are deployed for different requirements, like process planning or data-mining analyses and the related visualizations.

4. Data mining and annotation service

In this section an approach of stream processing on the focus of inline data mining analysis is presented. This evaluates the development of an agile information processing framework for HPDC.

The cycle time for one part on a die casting machine has a duration from 80s up to 130s. During this period the inline analysis must predict the decision, if the part can be delivered to the next manufacturing processes or if the part has to be rejected and melted back in the furnace. Fig. 4 illustrates the

data flow into the inline prediction process and into the batch process, which runs in daily periods.

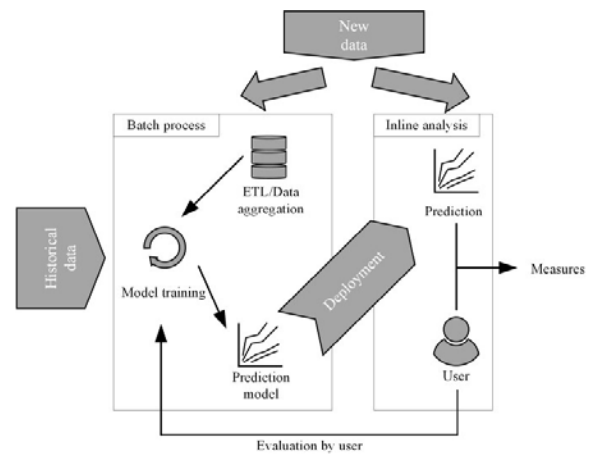


Fig. 4 Stream processing for inline data mining analysis

This prediction is based on a data mining model, which is trained every night in the batch processing layer. The collected data from every part of the last production day is used to train the data mining model and evaluates the prediction results. The information input to the batch process is accomplished by new data from measurement systems and quality information systems, by historical data from former casting projects and from a web based user interface for the worker, who evaluates the displayed prediction results by entering the real result. After training the data mining model, a prediction model is derived, which is deployed to the inline analysis stream. The described stream processing is inspired by the lambda architecture in big data technologies and deployed as a service.

Thus, the composition of different services is implemented in a task scheduler, who runs the services by distinct types of triggers (Figure 5). Signals from PLCs, tolerance limits of specific measurement values or simply periodically used time intervals are triggering the specific services for handling the data streams.

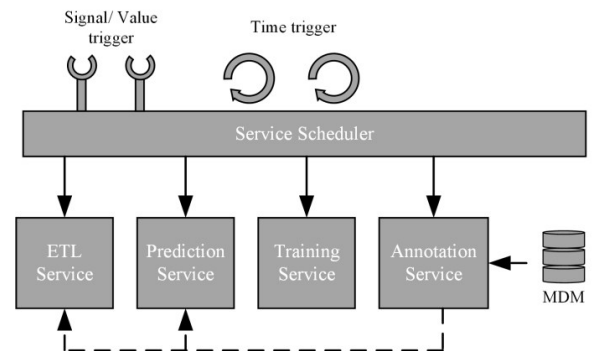


Fig. 5 Service composition in the HPDC framework

At last, the interoperability between different manufacturing departments or information systems is accomplished by an annotation service. A master data management (MDM) repository is designed for each manufacturing line and provides the most important information about each data source or product. This information is annotated as additional metadata to the information storage, where the actual data is persisted. Databases of measurement systems are extended by metadata entities via the mentioned ORM in Hibernate. On field level, the usage of OPC-UA enables labeling the gathered information into the UA specific information model. Providing services ensure via open interfaces to other information systems. Therefore it is inevitable to specify dynamically the exchange format, for example in XML-files as OPC-UA or in another descriptive technology.

5. Conclusion and outlook

In this work, requirements for modern information processing systems for the production process of high pressure die casting were examined. The introduction of an agile approach was highlighted by different technologies, as OPC-UA on every level of the automation systems and the implementation of a service oriented architecture. Due to that, the dilemma of holistic vertically and horizontally integrated information system can be solved.

Hence, the heterogeneous information structure in the foundry use case is presented and a solution for a pervasive traceability approach is presented. The initial situation concerning information systems in HPDC is solved by an implementation of a modular and agile information processing framework. The complex requirements on measurement and quality recording systems are fulfilled by the described framework. By annotating every gathered data, information about the origin of data regarding the process chain is not lost and can be aggregated easily by dynamic ORMs. For batch driven stream processing, the new type of inline analyses stream process was introduced and enables fast visualizations and web based technologies provide an independent deployment on every device.

The next step in research of agile information processing systems could be the implementation of domain specific ontologies with the goal to match it on a variety of differing companywide ontologies. As a result of that, every information in one company is included in one holistic system and leads to accomplish the goals of the smart factory approach.

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