Data Management System for Drive-based Smart Data Services
A Pratical Approach for Machine-Internal Monitoring Applications

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Abstract: In the field of machine tools, a continuous trend towards automated and networked production systems is recognizable in order to cope with the autonomous and self-organized systems promoted within Industry 4.0. For this purpose, large quantities of partially unstructured data exist within the machine-internal control system. The informational value of this data can be enhanced by suitable algorithms and utilized for multivalent applications. In addition to the information of the computerized numerical control such as feed rate or axis positions the drive systems of machine tools can be consulted. The major advantage of the drive internal information is due to the high temporal resolution of the available data, which is significantly above the interpolation cycle of modern CNC (e.g. Siemens 840D sl). However, a major obstacle is the access to this information, since most of the parameters are processed directly in the drive internal control loops and therefore not transmitted to the superordinate control. Within the paper, a practical solution for the automatic acquisition and processing of drive data is presented. Based on a machine internal data management system in combination with an industrial embedded system the extraction and aggregation of control loop data in the sense of so-called Smart Data Services is realized.

1 INTRODUCTION

In the course of Industry 4.0, an increasing demand for self-monitoring systems can be derived in the field of production systems. To meet these requirements, a variety of approaches with the goal of a holistic monitoring of machine tool exist. (Teti et al., 2010) provides a detailed overview of the historical development of sensor-based systems as well as their application in research and industry. (Matsabura and Ibaraki, 2009) and (Bindu and Vinod, 2015) focus more on the monitoring of production processes by measuring the prevailing cutting forces. The authors discuss not only the sensory acquisition of the measured quantities but also the utilization of signals from the feed drives.

In addition to these methods, innovative research approaches using the drive-internal control circuits to evaluate their fundamental functionality were developed in recent years. For example, (Schoenherr, 2012) examined a method for the assessment of the speed control loop based on the Prony analysis. In contrast, (Quellmalz et al., 2014) pursues an approach to access the quality of the speed control loop by easily evaluable index values based on a parallel comparison model. On the other hand, (Hellmich, 2014) uses highly sampled control loop signals for a process-parallel estimation of control plant parameters like total moment of inertia or effective friction torque.

All these methods have in common that they require specific control loop-internal signals with high temporal sampling (sample rate $\geq$ 1 kHz). For this purpose, modern production systems already have a large number of integrated information sources. However, these sources have mostly been insufficiently included in the performance monitoring of the machine tools. This is due to the fact that the underlying data is difficult to access and therefore its utilization is limited to machine-internal purposes, for example the control of the feed axes.

On the other hand, the use of network technologies in the production environment increased in recent years. As a result, the volume of communication partners and interfaces has increased significantly, which led to an accelerating networking of production systems with their environment. Apart of real-time capable interfaces to

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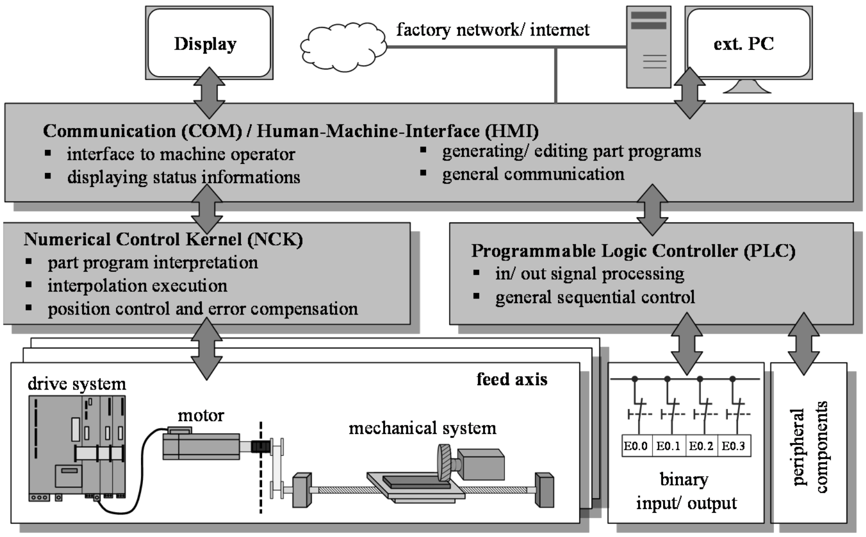

Figure 1: Structure of a typical computerized numerical control (Hellmich et al., 2016).

field devices (e.g. sensors, actuators), the interfaces to the corporate network, which have lower or no real-time requirements, should be mentioned in particular (Weck and Brecher, 2006).

Consequently, the main goal of the paper is the utilization of these interfaces to establish a consistent information chain from the feed drives via the CNC to the cloud. This forms the basis for control loop-based monitoring methods. At the beginning, an analysis of modern control systems including the underlying communication channels will be carried out (section 2). Subsequently, a novel systematic approach for an automatic drive data acquisition is presented (section 3). Section 4 is focused on the machine-level integration of the proposed method using an industrial embedded system available on the market. By implementing an exemplary identification algorithm, the functionality of the system is validated and an outlook for future developments is provided.

2 CONTROL OF MACHINE TOOLS

In the field of machine tools, a higher-level machine control is needed to realize an automated production process. This superordinate control can usually be assigned to the class of computerized numerical controls. As shown in figure 1, the structure of such a CNC can be subdivided into three essential functional components. The COM part, also referred to as the Human Machine Interface, allocates the interface between the operator and the controller and contains all operating, display and communication functions. The PLC part is used to adapt the CNC to the respective machine type. Structurally, it corresponds to a programmable logic controller and is utilized for signal processing of binary inputs and outputs as well as for coupling various peripheral components. In addition, the user has the opportunity to integrate own specific functions. The numerical control kernel realizes the main functionality of the machine tool control like path control, interpolation and the associated generation of the motion setpoints. Typically, the position control of the subordinated axes is also implemented in the NC-Kernel.

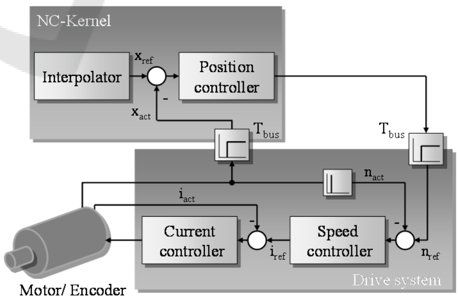

Figure 2: Separation of the cascaded servo control in electromechanical axes.

Whereas the data exchange of the controller internal components usually is realized via shared memory areas (dual-port RAM) (Siemens, 2010), industrial established fieldbus systems are common for the communication with the drive-internal control units. These systems are usually based on a specific communication protocol, which is divided into a cyclical and a user-specific, acyclical part (Profibus, 2006). Within the cyclical part, all parameter values relevant for the axis control (e.g. speed set point value, actual position value) are exchanged equidistantly in form of telegrams. Due to the classification of the control loops in the presented topology, not all control variables are transmitted from the drives to the control system by default. This can be partially avoided by expanding the predefined telegrams with the desired values (Siemens, 2011a). A second, acyclical data channel can be used for diagnostic purposes or the parametrization of the drives. By using proprietary read/ write services, a user-specific data exchange between the CNC and the drives can be implemented. This forms the basis for the proposed data management system in the following section.

3 SMART DATA MANAGEMENT BASED ON DRIVE DATA

In this section, the novel data management system with special focus on the provision of high-frequency drive signals will be presented. The overall procedure (figure 3) is divided into two main subsystems:

- A control-internal part, based on the fieldbus communication between the drives and the CNC and
- A control-external part, which includes the necessary communication functions as well as algorithms for data storage and aggregation

3.1 Drive Data Acquisition based on Controller-Internal Functions

Due to the high system clock, only the drive-side control modules are capable to record equidistant sampled drive data with the required high frequencies. For this purpose, the manufacturers of modern drive systems (e.g. Siemens Sinamics S120) already offer pre-installed measuring functions (trace-function), which are located directly in the control unit. This control unit works with a base clock of 8 kHz and thus meets the requirements of control loop-based monitoring methods (Siemens, 2011b). The trace function is primarily controlled during the machine commissioning phase via a corresponding engineering system. However, it is also possible to implement a remote control of this trace tool through dedicated list parameters.

The access to these parameters can be implemented with the already mentioned read/ write services of the PROFIBUS or PROFINET connection. Targeted utilization in form of a state machine allows an automated recording from the PLC part of the control. The basic functional process is illustrated in figure 4. First, the essential recording parameters (signals, recording cycle, duration, etc.) are parameterized in a configuration data block in

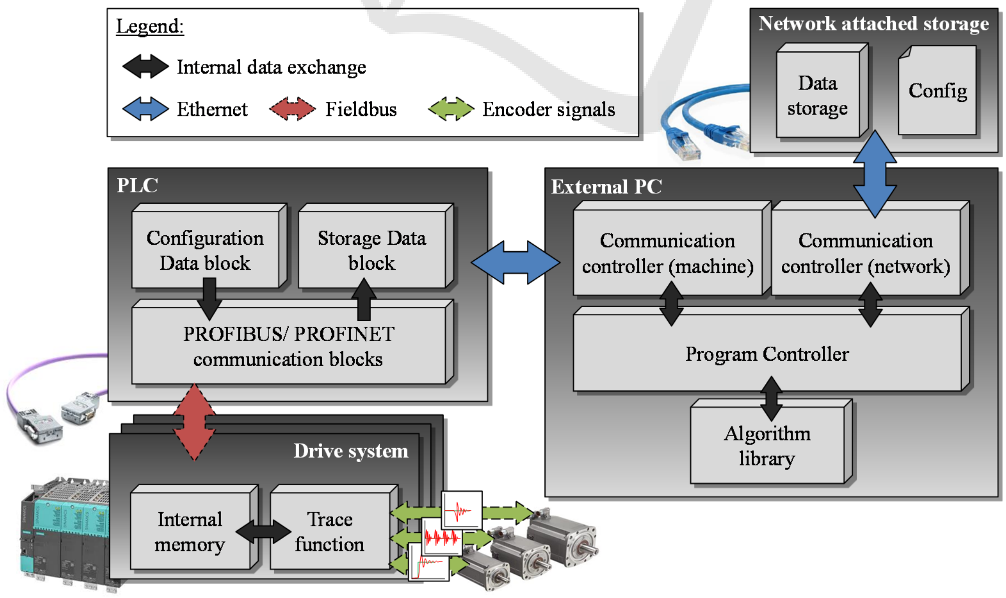

Figure 3: Structure of the drive based data management system.

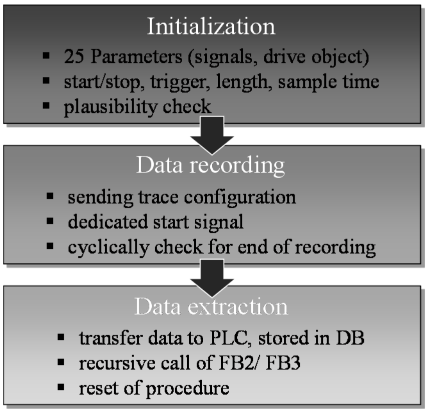

Figure 4: Sequential scheduling of control internal drive data acquisition.

the PLC part of the CNC. The transfer of the configured data to the drive control unit is implemented via the function block FB2, which is part of the default PLC-configuration. Subsequently, the recording in the drive system is started immediately or after a specific trigger condition occurs (e.g. motor torque exceeds a configured value). After completing the measurement, the signals are stored in dedicated data blocks in the PLC. The recorded signals are transferred via cyclical calls of the function block FB 3. Due to manufacturer-side limitations the signals are transmitted in packages of eight values each. Further details on the procedure and the underlying functions are described in detail in (Hellmich et al., 2016).

In comparison, the procedure described there was restructured for an utilization in the intended overall scenario. All parameters have been integrated into a multi-instance function block, which serves as the basis for the external access and offers benefits in terms of memory utilization and computing power.

3.2 Automatic Data Extraction and Processing

After transferring the measured values to the PLC, a central storage and enhancement of the informational value in the sense of so-called Smart Data Services is intended. Due to the limited memory capacity and the cycle time dependent on the program scope, this part of the CNC is not suitable for permanent storage or further signal processing.

As mentioned in section 2, however, modern control systems have the standard possibility of the integration into the company-internal Ethernet network and thus to realize the coupling of a personal computer with sufficient computing power. There are various software interfaces already available on the control side, for example to transmit centrally generated part programs or for remote maintenance. As part of the overall concept shown in figure 3, an Ethernet-based software tool called Snap7 has been determined, which provides the essential functions for a bidirectional data exchange between the PLC and external computing technology in a corresponding library (Nardella, 2015). In addition to preinstalled communication functions, various options for implementing personalized read and write requests are included. The novel created software application works according to the client-server principle and thus allows a data exchange between the machine control and the connected computing technology. The particularly developed program was designed to be scalable in order to prospectively enable the support of other control manufacturers without extensive adjustments.

Functionally, a distinction can be made between three essential components. An algorithm library (module “calculations”) accommodates all functions for the further processing of the logged drive data to the mentioned control loop-based Smart Data Services. This also includes the algorithm-specific parametrization of the trace function. All required communication functions were implemented in so-called communication controllers. Their task is the control-side access and thus the transmission of the trace parameters and the recorded data. On the other hand, additional communication partners such as the central server for data storage are included. The coordination of communication and calculation is handled by a central process control whose basic structure is illustrated in figure 5.

At the beginning, a machine-specific configuration file located on the central server is loaded which contains all required parameters. Subsequently, the parametrization of the control-internal data recording is initialized. After the extraction of the data stored in the controller, the calculation of the respective Smart Data Service and a cloud-based backup of the results for further analysis (e.g. trend analysis, data mining) as well as their visualization take place.

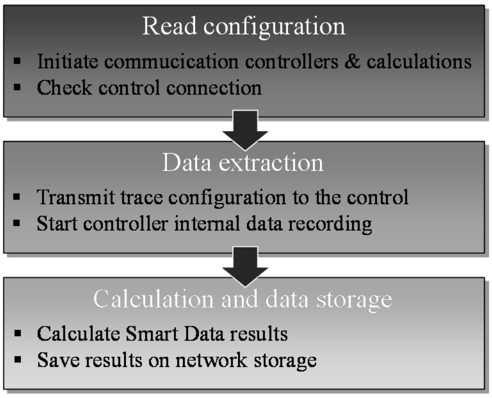

Figure 5: Sequential scheduling of control external data processing.

4 HARDWARE-IMPLEMENTATION AND FUNCTIONAL VALIDATION

In this section, the previously presented method is integrated in an exemplary machine control using an industry-standard embedded system and is validated by utilization of an exemplary identification algorithm.

For control external implementation, a scalable, Linux-based computing system called Revolution Pi developed by Kunbus was defined. Its main component is a multi-core processor which is architecturally based on a conventional Raspberry Pi. The core module is already installed in a rugged profile rail housing by the manufacturer and meets all standardized requirements for the industrial utilization of programmable logic controllers. In addition to simple control cabinet integration, it is also possible to connect various gateways, for example for the communication via customary bus systems or in form of digital and analog input and output modules. The data exchange with the CNC is realized via an Ethernet connection as explained in the previous section. Due to the limited memory capacity of the embedded system (4 GB), the configuration of the procedure and storage of the results is located on the central server. In addition, the controller-internal data acquisition was integrated in the PLC part of the control.

For the experimental verification, a method for a noninvasive identification of control plant parameters developed by (Hellmich, 2014) was selected and adapted for industrial purposes. This modular method estimates actual values for total moment of inertia and friction torque of the considered axis based on high sampled drive signals, in particular actual motor speed and torque.

First of all, a conceptual classification of the underlying modules of the procedure into the extended control architecture was carried out. Thus, a part of the modules (data acquisition, signal pre-processing, excitation detection) was implemented within the control, whereas the majority of the calculations are performed on the Revolution Pi. The division of the modules into the individual components is illustrated in figure 6. For more detailed information of the underlying method see (Hellmich, 2014) or (Schoeberlein, 2016).

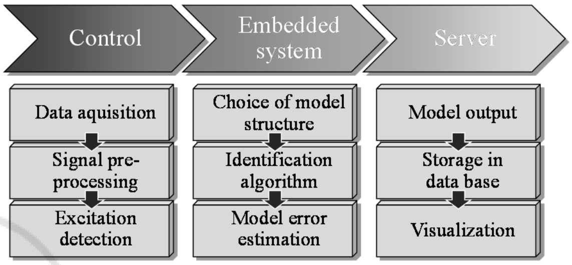

Figure 6: Integration of the non-invasive identification algorithm into the novel data management system.

All subcomponents were integrated on a three-axis test rig with a commercially available Siemens-CNC (Sinumerik 840D sl). In order to validate the method, an exemplary selected feed axis was excited with a sinusoidal velocity profile. The actual values of the recorded signals for motor speed and torque in x-direction are shown in figure 7. As it can be seen in the enlarged view, the recording was performed with a sampling clock of 500 µs. A measurement of these values with such a high resolution is only feasible in the drive-internal control modules. In addition to the high-frequency signal recording, an exemplary parameter identification was performed based on the measured signal profiles. A comparison of the calculated moment of inertia and friction torque based on construction data as well as experimental preliminary investigations shows a good agreement (table 1). From this it can be concluded that the combination of Smart Data Management System and drive-based Smart Data Services located in a fully-integrated embedded system is suitable for machine-internal monitoring functions.

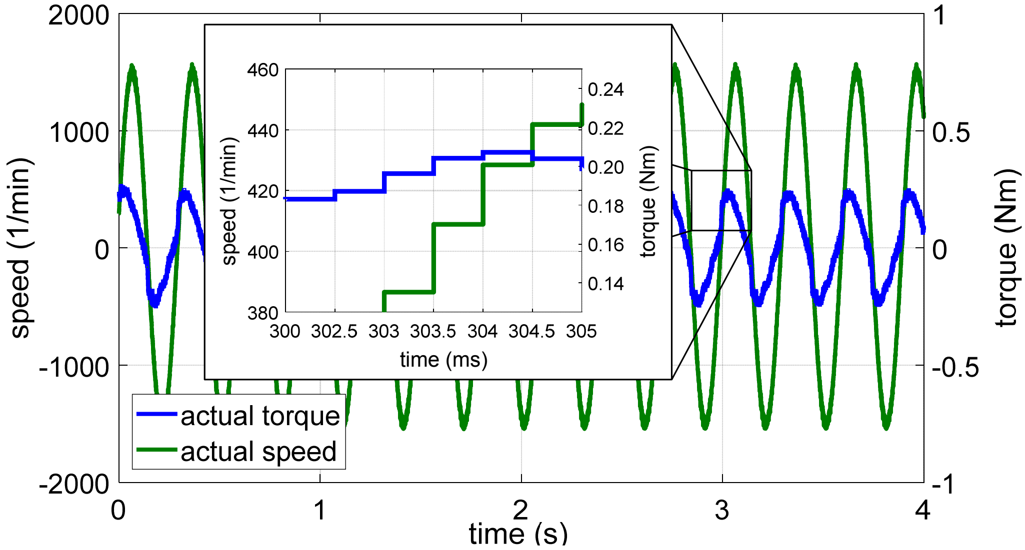

Figure 7: Recorded values for actual motor speed and torque.

Table 1: Comparison of the identification results with theoretical calculations.

Calculation results	Identification results	Δ [%]
$J_x = 34.46$ kgm²	$J_x = 34.67$ kgm²	$J_{x,\Delta} = 0.6$
$T_{R,x} = 0.051$	$T_{R,x} = 0.057$	$T_{R,x,\Delta} = 10.5$

5 CONCLUSIONS

In this paper, current research results in the field of drive-based Smart Data Services for production systems were presented. In addition to the establishment of a control-internal data management system for the acquisition of control loop data, the machine infrastructure was selectively expanded by integrating an embedded system available on the market. This allows the machine-level processing of cyclical logged drive data and their informational enhancement to significant characteristic values. Furthermore, a global data store has been set up, which ensures the availability of all measured signals as well as calculation results and can serve as a basis for further applications.

The core idea of the research project is the manufacturer-independent networking of production systems as well as a central data provision and further processing in the sense of Smart Data Services. For this reason, in the next step, possibilities for connecting further control manufacturers (e.g. Heidenhain) and an associated drive data acquisition has to be realized. Due to the architectural differences in the control systems, new approaches are needed here. Subsequently, further control loop-based monitoring algorithms should be implemented and investigated for their suitability by long-term tests. At this point, the earlier mentioned control-loop based algorithms as performance index (Quellmalz et al., 2014) or Prony-Analysis (Schoenherr, 2012) are eligible to improve the understanding of the control behavior parallel to the process. Furthermore, it would be conceivable to use the results directly to adapt the drive control parameters online and thus react to changing circumstances. Due to the conceptual design of the data management system, in addition to the extraction of the drive data their targeted adaption is feasible.

The conclusion is the expansion of the data infrastructure, for example considering the global availability within the network storage or the parallel recording of machine and additional sensor data. Subsequent correlation and pattern analysis will provide new insights into the state of production systems and contribute to autonomous, cyber-physical systems in the sense of Industry 4.0.

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