A Process Oriented Approach to Automated Quality Control

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Abstract

To guarantee a constant quality of manufactured products, it is necessary to optimise the process parameters immediately when deviations of the workpiece quality have been observed. Established methods of quality management are only able to register quality deviations (like the statistical process control) or to analyse them offline with the help of experts (like failure mode and effects analysis). The presented approach develops a process oriented automated quality control for manufacturing in two steps: First, a local quality controller stabilises the product quality to reference values in the pace of workpiece production. In order to obtain the control law for the process parameters, a learning approach is applied. In the second step, the information exchange between the local controllers is established parallel to the workpiece flow in order to obtain an optimised global process. As an example, the method is applied to quality control in the turning process.

Keywords: Quality Assurance, Distributed Control, Holonic Manufacturing System

1 INTRODUCTION

In general, a complete manufacturing process can be modelled as a sequence of local manufacturing subprocesses numbered by $i=1,...,n$ in Figure 1. Starting with the raw material, the workpieces are processed in the subprocesses in ascending order until the final product is obtained.

In each subprocess, the quality of the product is threatened by systematic and random errors. For that reason, the workpiece quality must be measured and a strategy has to be found, to use the measured data in order to compensate at least the systematic errors. In most cases the relation between the process observation and its control is highly nonlinear and classical methods of linear control theory cannot be applied. In most cases, it usually depends on the process knowledge and experience of the operators to adjust the parameters of the machine manually.

Quality Control and Quality Management

In the recent years, methods of process control have been developed. The statistic process control (SPC) investigates the measured data with statistic methods in order to predict developments within a subprocess for the near future and to give a warning, if a requirement for quality is violated [1].

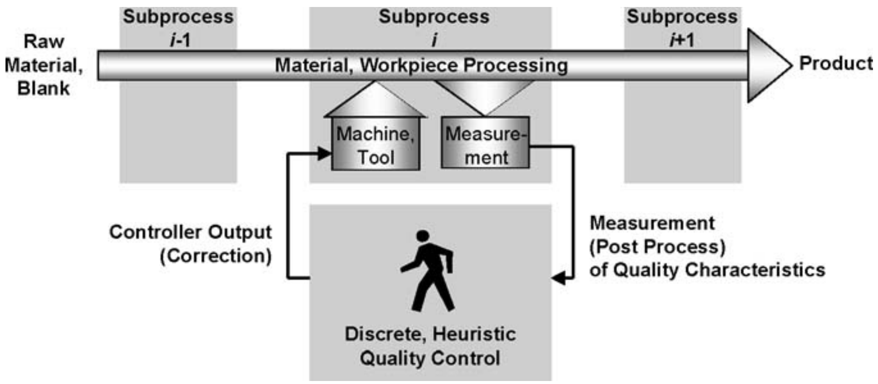

Figure 1: Subprocesses and heuristic quality control.

If deviations are observed at the end of a subprocess, the failure mode and effects analysis (FMEA) can be used in order to list up possible reasons for failures and to develop suggestions for an improvement [2].

Both methods will support the process operator, but they are not able to define an appropriate control action to optimise the workpiece quality immediately and automatically in a closed loop as shown in Figure 1.

Quality Control and Control Theory

It is characteristic for a controlled closed loop system, that the determination of the controller output is based on a continuous measurement as well as on reference values [3].

The same situation can be found for the case of quality control: The correction of the controller output is determined continuously in the pace of the process from measurement which quantifies quality characteristics of the product (see Figure 1). It is compared to quality reference values.

For the investigated class of production systems, the following properties can be summarised:

- Since an in-process measurement is impossible or too expensive in most cases, the approach is restricted to a post-process measurement at the end of each subprocess. This can be applied to discrete manufacturing and to batch processes. Hence, the system is discrete in time; the post process measurement limits the time pace.
- Measurement is related to the product, whereas the controller output is applied to the process. In classical control theory both values are related to the process.
- It is not sufficient to operate the system in one setpoint. Hence, the relation between measurement and controller output is nonlinear in general.

- In most cases, no mathematical model of this relationship is available.
- For real plants, multiple inputs and outputs must be considered (MIMO system).

For the classical controller design, a mathematical model of the plant is necessary. In the same way the idea of a model based quality control has been developed [4] which uses a model for the interpretation of the measured data. The control unit has to determine its output such that according to the model the measured deviation will be compensated as good as possible.

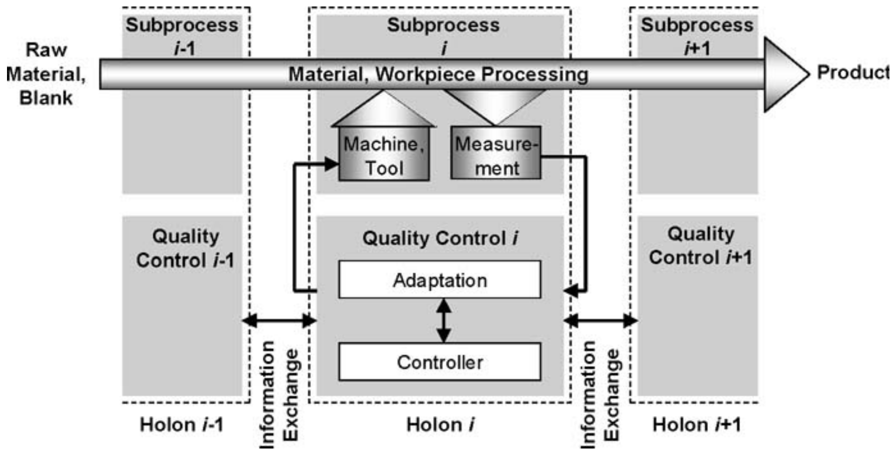

Figure 2: Quality control as a part of an Holonic Manufacturing System.

The problem remains that the model has to be developed, which is a time consuming and difficult task in most cases. In section 2 a learning algorithm is presented that is able to obtain a process model from measured data samples. It shows a fast adaptation of the control law within a sequence of a few workpieces. Especially in cases where a sequence of similar workpieces has to be manufactured, the method seems to be advantageous to reach an optimised workpiece quality.

Quality Control and Holonic Manufacturing Systems

The described quality control of a single subprocess can be improved by an information exchange to the preceding and following subprocess as shown in Figure 2. By this way, the local system receives information about the demands of the complete production chain that can be considered locally.

The local subprocess and its control can be regarded as an autonomous unit. It is able to cooperate with other units. These units can be integrated to larger systems, which model production chains.

Such a unit is called holon within the concept of Holonic Manufacturing Systems [5], [6]. Therefore, the concept presented in section 3 contributes to a quality related manufacturing holon.

2 QUALITY CONTROL OF A LOCAL PRODUCTION STEP

2.1 Concept

The measurement is received in the pace of the workpieces passing through the production chain and the control output is determined once for each workpiece. The process can be characterised as a sequence (numbered by k) of measuring vectors $\boldsymbol{y}(k)$ and vectors of control actions $\boldsymbol{u}(k)$.

Within the general concept, a diagnosis unit (see Figure 3) is used

- to calculate the quality characteristics of the product and
- to determine additional machine state information (if necessary)

from measurement. The result is summarised in the state vector $\boldsymbol{z}(k)$.

For the automation of the manual quality control shown in Figure 1, an appropriate controller structure has to be developed. The control problem is to find a controller output $\boldsymbol{u}(k)$ such that the current state $\boldsymbol{z}(k)$ is changed into the reference value $\boldsymbol{w}(k)$. In general, this may need a sequence of steps k until $\boldsymbol{w}(k)$ can finally be reached. But, in the present case of quality control a new workpiece is received in every step and a controller output has to be found that leads to an optimal processing within this step.

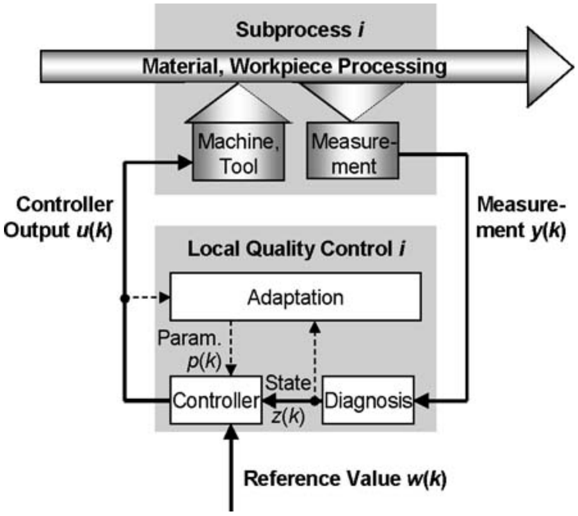

Figure 3: Structure of an automatic local quality control.

2.2 Adaptation of the control function

For this system a learning algorithm is proposed that uses the data [$\boldsymbol{u}(k)$, $\boldsymbol{z}(k)$] for the adaptation of the parameters $\boldsymbol{p}(k)$ of the control law (see Figure 3).

At the end of each process step the control output $\boldsymbol{u}(k)$ and the state information $\boldsymbol{z}(k)$ are inquired. The question arises, how this sample can be used to improve the control law. Assuming that the obtained quality characteristic in $\boldsymbol{z}(k)$ would just be the expected reference value $\boldsymbol{w}(k)$, the corresponding optimal control output would exactly be $\boldsymbol{u}(k)$. Using this interpretation, a training set for the control law is obtained.

2.3 Representation of the control function

Next, a functional representation f_c which maps the input $\boldsymbol{x}(k)$=[$\boldsymbol{w}(k)$, $\boldsymbol{z}(k)$] into the output $\boldsymbol{u}(k)$ is needed:

$$\boldsymbol{u}(k) = f_C(\boldsymbol{w}(k), \boldsymbol{z}(k)) = f_C(\boldsymbol{x}(k)) \tag{1}$$

Comparing the sample and the training set, the input and the output are just exchanged. So, the demanded control law can be taken as the inverse function of the process plant. As a representation of the control law, a linear superposition of radial basis functions $\theta_j(k)$ is used to map the controller inputs $\boldsymbol{x}(k)$, to the output $\boldsymbol{u}(k)$ (see [7], [8]):