IFaCOM Report Summary

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Final Report Summary - IFACOM (Intelligent Fault Correction and self Optimizing Manufacturing systems)

Executive Summary:
The vision of IFaCOM is to achieve a near zero defect level in all kinds of manufacturing, with emphasis on production of high value parts, on a large variety of custom design manufacturing and on high performance products. This shall be achieved through:

• Improved performance process control to reduce defect output and reduce the costs of defect avoidance
• Enhanced quality control to obtain more predictable product quality
• Enhanced manufacturing process capability independent of manufactured parts

The objectives of the project are to reach a level of excellence for a systematic body of knowledge on near zero defect manufacturing through improved process control, and long-range stability by use of intelligent manufacturing quality control systems.

In IFaCOM, this has been obtained through the development of new manufacturing strategies and methods which has been demonstrated in industrial cases. These methods have been designed in order to operate on three levels:

• closed loop control of vital parameters based on in‐process real-time measurements
• medium time process tuning and optimization based on analysis of complex data sets
• optimized machine system for long-range performance improvement.

Project Context and Objectives:
The concept of six-sigma was introduced by Motorola to improve the performance in high volume production of standardized products. It was based on the methods of statistical process control and has given substantial results in mass production, ensuring stable production with fault rates down to the order of 1-2 parts per million. This level of excellence can be transferred to other branches of industry that work with small/medium batches. Many of the companies belonging to this last category manufacture products that must meet extreme specifications. Defects in their products are simply not accepted. Therefore, the companies do put an extreme effort on checking, repairing or remaking parts to meet the specifications. For these companies the term “beyond six sigma“ means improved methods and new process control methods that enables “make it right first time” manufacturing.

The basic philosophy is to reduce the variance much in the same way as in six sigma controlled volume production. The essential thing is to reduce all sources of variation, and to develop a method to eliminate the detrimental effects of unavoidable variance in material, part and processes quality that is the major source of defects in many manufacturing processes. To control this variance, it is necessary to identify its sources, developing methods that reduce the cost of eliminating the effects of this variance a posteriori

A crucial aspect of developing and implementing effective diagnostic and prognostic technologies is the ability to anticipate/predict faults’ onset in order to take actions that help preventing their occurrence. Fault isolation and diagnosis uses the detecting events as the part of the process for classifying the faults within the system being monitored. Condition and failure prognosis forecasts the remaining useful life and enables temporary stop of operations and resetting before
proceeding. Within IFaCOM, methods such as Data Mining and Knowledge Discovery, and Evolutionary Optimization techniques have been investigated and their applicability in modern manufacturing environments evaluated.

As mentioned above, different process control strategies can be adopted, depending on the severity of the detected event and the time requirements of the corrective action.

In real-time control of vital parameters, the control loop must be fully automatic. In fact, only direct measurements of vital parameters and a quick data processing can ensure that proper reaction will take place in response to detection of an unwanted state within milliseconds.

For medium-term optimization, process simulation-based approaches have been developed to predict the process behaviour from the knowledge extracted from measured data. These approaches allow a continuous compensation of the allocation and distribution of part qualities across the entire process chain based upon the current measured status of the part-process-system qualities. This provides a global optimization of the entire process chain and can also be adapted to small lot sizes.

For long-range optimization of process parameters and maintenance, human judgment should be part of the loop to ensure that tacit knowledge about the process is included in the optimization loop. In IFaCOM, the use of modern computational intelligence methods has allowed to augment this knowledge through the analysis of complex data, ensuring that hidden patterns and trends are brought to the attention of the human operator.

Project Results:
During the IFaCOM project different types of activities have been carried out.

a) RTD
b) Application and demonstration
c) Dissemination and exploitation
d) Management

The main function of WP1 has been supervising the project RTD activities and conveying their results into the demonstrators. The first activities were focused on creating a common understanding on processes and available technologies/methodologies for improving the production quality. Information from industrial partners have been collected via several questionnaires. Based on the data retrieved, the consortium has performed a detailed analysis of the end user processes and products, with a special focus on current technologies applied in production lines at the end users factories for reducing the scrap rate. Within this analysis, end users have stated their research priorities (user requirements) and critical steps in the targeted production processes have been identified, presenting several proposals for heading towards zero defect manufacturing. In addition, technology suppliers have presented their core technologies and their potential developments for solving the identified criticalities or for providing useful tools for the IFaCOM system.

WP2 has focused on establishing sensor systems solutions and strategies for the real-time assessment of the status of the manufacturing system, the manufacturing process and the part during operation. This work started from the development of methods for the identification of part-process-system vital parameters realized in WP1 and encompassed the characterization of functionality and capabilities of sensor systems, selection of optimal sensor solutions, development and implementation of optimal hardware and software solutions for integration of sensor systems in machine tools and in aerospace processes. The capabilities of the developed sensors systems solutions have been demonstrated by implementing them into the project’s end user cases.

This WP has developed new methods and systematic approaches for validation, structuring and storage of acquired data as a preparation for data processing. As a result of a measurement, information about the product and production process is gained which can be used for production control. The information quality strongly depends on the measurement process which can be described by multiple parameters like the measurement uncertainty, the measurement point density etc. A very important parameter with respect to a zero defects quality level is the level of integration into the production process. While the results of in-line or in-process measurement systems can be used for quasi real-time production control, post-process measurements can only be used for a long-term process control. On the other hand, in-line or in-process measurements have to be performed
within the production cycle and within production environment. In many cases, this leads to a higher measurement uncertainty. Today, there exists no systematic approach to design a measurement process with respect to all parameters which are relevant for production control. In many companies, measurement processes are designed only with respect to the specified feature tolerances. To achieve a near zero defects manufacturing level, it is therefore necessary to enhance the conventional approach to describe and design measurement processes with respect to their use for production control. An organizational structure has to be defined which supports an early consideration of measurement processes in the setup of manufacturing processes.

WP4 has coped with the processing of the sensor signals acquired by the sensors selected within WP2 and applied to the manufacturing processes selected in WP5 and WP6.

The first step in this direction has been sensor signal feature extraction, carried out in the time domain, in the frequency domain and in the time-frequency domain. Signal features must describe the signal adequately and maintain the relevant information about the process conditions.

For time domain feature extraction, several features have been extracted (arithmetic mean, average value, magnitude, root mean square, variance, standard deviation, skewness, kurtosis, signal power, peak to peak range or peak to valley amplitude, crest factor, signal ratios, etc.) and different time domain feature extraction techniques have been selected and used depending on the application requirements (statistical analysis, time series modelling, principal component analysis, etc.). For frequency domain feature extraction other techniques have been adopted (fast Fourier transform, discrete wavelet transform, wavelet packet transform, etc.).

For evaluating the correlation between the original signal and the features and selecting features which are really representative of the signal, different techniques have been used (Pearson correlation coefficient, Taguchi’s orthogonal arrays, etc.).

When measuring a particular variable, a single sensory source for that variable may not be able to meet all the required performance specifications. A solution to this problem is sensor fusion that combines sensory data from disparate sources so that the resulting information is better than would be possible when these sources are used individually.

The sensor fusion approaches followed in the project are based on multiple sensor monitoring systems and direct fusion paradigms (i.e. fusion of sensor data from a set of heterogeneous or homogeneous sensors and history values of sensor data) and/or indirect fusion paradigms (i.e. sensor fusion that uses information sources like a priori knowledge about the environment and human input) selected as the most effective for the applications of interest for the project.

The framework chosen and developed within WP5 is identical for each demonstrator and manages to call the correct sequence of functions for the sensor data; it relies on a configuration file which adapts the software to the demonstrator by providing necessary preferences and matching sensor data with the (signal-) processing functions.

As seen in the data flow diagram, the system gets sensory data from a DAQ-System. The first step (data preparation) is to acquire this data and store it in the system in order to call the subsequent functions with this data. This can only be covered in generic software due to different hardware interfaces. For instance, some DAQ-Systems need specific drivers and therefore specific functions to establish a connection to the hardware and read the data. This applies particularly for sensors with their own DAQ-System. After the data is stored, the (signal-) processing functions are called. Depending on the information in the configuration file, the correct sequence of functions is called in order to extract the necessary features from the signal, which are correlated to the relevant process parameters. These features are also stored in a dedicated common data structure and are delivered, with additional information if necessary, to the decision making function.

The output of the decision making function includes a list of parameters with the corresponding adjustments. This information is sent to the machine controller. A common data structure within the software was defined in order to simplify the adjustments to the different demonstrators and to integrate new functions.

WP6 has defined, developed, implemented and validated a Simulation-based, Intelligent Fault Diagnosis and Prognosis System for Optimization over time (SIFDPS) so that the manufacturing of a part is achieved within its specified quality.

This system consists of the following three main sub-systems:

- A semantically enriched (with part quality definitions) part program system across the process chain (SEPM)
According to the developed method, the definition of a desired multi-stage part program is upgraded with a formal description of the desired part qualities, defining a Semantically Enriched Process Model. In the proposed approach, part quality errors (deviations from the reference part quality) are modelled and predicted as a function of the input process parameters, on-line process measurements and real manufacturing system states. According to this method, it is the reference part quality that indicates the desired ranges of values for the related vital quality characteristics (VQCs).

- A knowledge-based representation of the manufacturing system performance across the process chain.
- A method has been defined for specifying the reference manufacturing system performance as function of the process load (demand) as well as the physical limits of manufacturing system.
- A simulation-based sub-system that provides process re-planning suggestions across the multi-stage process chain by using the extracted knowledge from real-time measured data.

Within WP6, an intelligent self-adaptation and self-optimization methodology has been developed (process parameters adjustments suggestions system, PPASS). The methodology relies always on fuzzy logic for part quality prediction, fault diagnosis and process parameters adjustment suggestions. Fuzzy logic has been chosen due to its ability to account for vagueness/imprecision and nonlinear behaviour, which are common characteristics to manufacturing processes and systems. In the fuzzy-nets approach, the relationships between the inputs and the outputs of the manufacturing process are described through a collection of fuzzy control rules involving linguistic variables rather than a complicated dynamic mathematical model (differential equations). The most evident benefit of the implementation of the fuzzy-nets controller is related to the real-time process adjustments and mid-term process re-planning based on predicted part quality characteristics.

WP7 has focused on the implementation of R&D results into the demonstrators of the Aerospace sector.

GKN

GKN produces, amongst many other products, Turbine Rear Frames (TRFs). The TRF is a part of a jet engine, and is manufactured by assembling multiple components together in a toroidal structure. Current production of TRFs is highly dependent on manual operations, while the company wants to decrease these manual operations and substitute them with automatic operations.

The IFaCOM demonstrator at GKN focuses on demonstrating the automatic assembly and tack welding of components of a TRF section.

Europea Microfusioni Aerospaziali (EMA), part of the Rolls Royce group is a precision investment castings foundry for the production of turbine blades, vanes and component for the most modern jet-engines to civil and defence aerospace and power generation engines. EMA’s products are obtained using is the “lost wax” process and using mainly Ni-based superalloys. Ceramic inclusions problems are particularly relevant for the investment casting technology and represent one of the main sources of scraps in foundries.

WP8 has focused on the implementation of R&D results into the demonstrators of the Machine tools sector.

ALESAMONTI

Alesamonti is a manufacturer of boring/milling machine tools. Every structural component of its machines is manufactured internally, often using Alesamonti’s machine tools for boring/milling processes. Some of their components, produced in small batches, are quite big while their tolerances (flatness, squareness and parallelism) are typically within 50 μm. For making the first part right, and avoid/reduce expensive and time consuming reworking and manual fitting of their components, they need to perform a thorough control of their processes.

Therefore, their focus within the IFaCOM project has been on isolating and deeply analysing possible sources of geometric
errors (part, machine, process) and to develop tools for controlling their processes, increasing their chances to have a zero defect manufacturing

**STRECON**

Strecon has developed a new machine system for surface polishing of industrial tools and machine components. The technology is based on an industrial robot and known as RAP (Robot Assisted Polishing). The RAP machine consists of a part-holding spindle and a polishing module with controlled contact force held by an industrial robot, providing for spatial movements in the machine workspace. The spindle, driven by a direct-drive servomotor, provides either for rotation of an axisymmetric part or indexing of a stationary part. The polishing module with air-pressure controlled contact force provides either an oscillating (reciprocating) linear tool movement or a rotating tool movement.

**AGIE CHARMILLES**

Georg Fischer Agie Charmilles (GFAC) is a manufacturer of high precision machine tools which use a metallic wire (electrode) to cut a programmed contour in a workpiece (wire EDM, Electric Discharge Machining). Current practice of WEDM is not defect-free and still a number parts produced by WEDM processes are rejected due to surface quality defects. The main defects related to surface quality of WEDMed parts include: occurrence of “lines” and “marks”, surface roughness, and recast layer (also called white layer).

Potential Impact:
Since the beginning, IFaCOM has focused and prioritised industries and industrial applications. Throughout the course of the project, the consortium has developed a methodology for the achievement of zero defect manufacturing. The methodology has been proven effective in different industrial scenarios, both in the aerospace and in the machine tool field. Due to the variety of cases addressed, and to the peculiarities and constraints of each of them, it is difficult to systematically generalize and extend project results to the European machine tool and aerospace industries. In fact, depending on several case-dependent factors (the application, the size of the company, the centrality of the machine/process in their production, the cost of the installed control system, the development stage reached during the project etc.), the impact of the improvements made within the project changes considerably. Nevertheless, project achievements have been reviewed by each end user and their evaluations show promising trends in terms of

- Improved quality. Application of the ad hoc developed equipment has allowed to significantly reduce defects in quantitative (number) and qualitative (entity, dimensions) terms (i.e. reduction of inclusions, EMA)
- Increased predictability of quality. Increased data availability allows to analyse and predict production’s outputs. Also, some developments done within the project (i.e. e-tracking system, GFAC) allow to predict, identify and localize defects, reducing the effort of post process quality controls
- Increased throughput / productivity. Process automation, process monitoring and control allow to reduce the time cycle and time consuming side-activities (quality checks, rework, fitting operations) increasing the overall company throughput (i.e. Strecon, GKN)
- Improved robustness of processes or product. More stable and repetitive processes reduce the variance of quality results (i.e. GKN, GFAC)
- Reduced direct human labour costs and expenses. Automation and intelligent process control leads to a reduced use of manual labour and, consequently, reduced costs (i.e. GKN)
- Reduced process cost. Faster and more efficient machines and processes allow to reduce single process cost (less human supervision, manufacturing time reduction, less waste)
• Reduced material cost. Quality improvements lead to less scrap parts and less material waste, more predictable tolerances and allow to optimize the design of components reducing material usage (i.e. Alesamonti, reduced manual fitting activities)
• Reduced quality control cost. As described previously, online process control costs less than post process control
• Increased process know how. Data availability has a direct effect on companies know how on their processes, allowing data analyses and interpretation, better process understanding and possibilities of future improvements
• Improved data processing / interpretation. The application of machine learning/artificial intelligence methods allow to derive information on the process and make decisions otherwise difficult to extrapolate developing and using complex mathematical models (i.e. EMA, GFAC)
• Better use of human resources. Process control and automation allow to replace human operators in tasks that involve hard physical or monotonous work (i.e. GKN’s TRF bending and welding); workers can take on other roles, typically higher-level jobs running/supervising of the automated processes.
• Improved product competitiveness in the market. Intelligent machines and controlled/ certified processes guarantee better quality products and are more appealing for customers.
Also, some minor drawbacks have been identified
• Increased equipment cost. The use of additional equipment installed on machines lead to an increase in the equipment and installation costs.
• Increased maintenance cost. The use of additional expensive equipment require additional maintenance activities.
As expected, company heading towards an increased process control, automation and a zero defect manufacturing may face a high initial costs in purchasing technology and increase their maintenance costs, but, in the medium-long term, the introduction of new technologies showing all the (economical) advantages listed before, will pay back the initial investment. In fact, projects’ end users have a unanimous perception that the introduction of the IFaCOM methodologies and technologies will have a positive financial impact on their companies' gross margin in the medium-long term.
Among industrial players participating to the project, also technology suppliers have highly benefitted from the project results; in fact, they have developed new products or improved existing ones, establishing commercial relationships with new customers and enhancing their offer and their competitiveness on the market.
In order to broaden the impact of the project, several initiatives have been taken, including the formalization of the project best practices, several standardization activities and the clustering 4ZDM initiative, which involves the other 3 ZDM project and aims at integrating projects’ results, deriving a common strategy towards zero defect manufacturing.

List of Websites:
www.ifacom.org

Related information

| Result In Brief | Fewer defects by improving equipment reliability |
| Documents and Publications | final1-ifacom-final-publishable-summary-report.pdf |

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