Toolkit Conceptualization for the Manufacturing Process Reconfiguration of a Machining Components Enterprise

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Abstract

With the target of Zero-Defect Manufacturing, the European Project Industrial Data Services for Quality Control in Smart Manufacturing (i4Q) aims to develop 22 software solutions based on Artificial Intelligence (AI) to optimize manufacturing processes, ensuring quality, effectiveness and interoperability among manufacturing companies. The solutions will be implemented in real manufacturing scenarios, where the outcomes of the project will be tested and evaluated. One of the solutions, i4Q Line Reconfiguration Toolkit, will be deployed in FACTOR, a manufacturing company dedicated to metal machining and precision turning. This paper covers: (i) the introduction of the pilot case and the project solutions; (ii) the goal that FACTOR aims to achieve by the implementation of the solutions; (iii) the main features of the Line Reconfiguration Toolkit solution and their alignment with the requirements exposed by FACTOR, and (iv) the expected results when applying i4Q Line Reconfiguration Toolkit in FACTOR.

Keywords

Process reconfiguration, reconfigurable manufacturing systems, Industry 4.0, quality, zero-defects

1. Introduction

This paper is contextualized on the European Project Industrial Data Services for Quality Control in Smart Manufacturing (i4Q) [1]. To this end, i4Q aims to provide an IoT-based Reliable Industrial Data Services (RIDS), a complete suite consisting of 22 solutions, for assuring data quality, product quality, and manufacturing process quality, aiming at zero-defect manufacturing [2]. Amongst the technical RIDS toolkit, i4Q leads to build the i4Q Rapid Manufacturing Line Qualification and Reconfiguration, proposing a set of tools that support enterprises on their processes' qualification, reconfiguration, and optimization, leveraging process data intelligently.

This paper is focused on the conceptualization of the Manufacturing Line Reconfiguration Toolkit (i4QLRT) solution that consists of a collection of optimization micro-services that use simulation to evaluate different possible manufacturing processes and aid as a tool when the process parameters need to be reconfigured for achieving the required quality of the product and process objectives. All the i4Q RIDS solutions are designed according to the industrial scenarios' requirements, which are defined by the enterprise pilots that participate in the project. Six are the industries that participate in i4Q project, operating in different industrial sectors, including metal and wood industrial equipment, white goods, metal machining, ceramics pressing, and plastic injection. This document is centered on

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the requirements of the metal machining enterprise (Figure 1), FACTOR Ingeniería y Decoletaje S.L, that will allow to conceptualize the functionalities of the i4QLRT solution, taking into account FACTOR current needs for the reconfiguration of the manufacturing process.

FACTOR Ingeniería y Decoletaje S.L [3] is a manufacturing company located in Valencia (Spain) dedicated to metal machining and precision turning. FACTOR works for the most restrictive sectors of the industrial network, namely aeronautics, automotive or medical. The main challenge of the enterprise is ensuring the quality of the products, avoiding defects during the production, which would be translated into a reduction of costs, an increase of efficiency, and higher customer satisfaction.

During the computerized numerical control (CNC) machining process, many factors rule the dimensional and aesthetic quality of the manufactured parts and that is why quality control of the parts must be carried out during the production process. This while-producing quality control is complex, takes a lot of time, and requires expensive measuring equipment. It is also not a 100% effective that causes scrap and all the data collected from the measurements are only analyzed for that specific production. FACTOR will exploit the i4Q RIDS to make a 100% while-producing quality control of the manufacturing, and will use all the data obtained to anticipate future manufacturing problems by treating this data with algorithms.

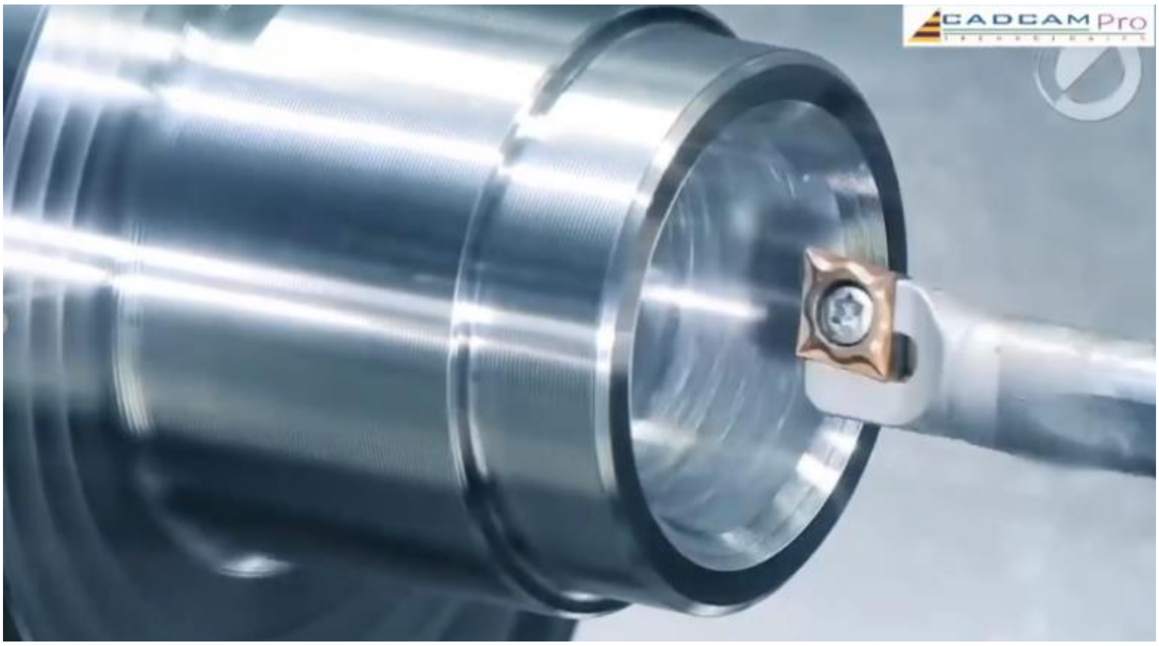

Figure 1: FACTOR machining

The Rapid Manufacturing Line Qualification and Reconfiguration is supported by the data quality, data analytics and manufacturing quality methods and tools developed within the i4Q project. In this regard, algorithms for process reconfiguration will be fed by enterprise legacy systems and newly added sensors. The Rapid Manufacturing Line Qualification and Reconfiguration solution addresses the (i) continuous process qualification to determine that outputs are within limits; (ii) detection of defect causes by recommending corrective actions; (iii) processes' simulation to model different scenarios; (iv) optimization to reconfigure the production process; and (v) reliability of data collected. These characteristics fulfill the aforementioned FACTOR needs.

2. Process reconfiguration problem in a machining parts enterprise

Manufacturing companies must be able to meet the market requirements given by the frequency increase of new products introduction, the shortening of their life-cycles, changes in a part of existing products, changes in government regulations, large fluctuations in product demands, and changes in process technology [4-6]. The manufacturing systems that operate in this context will have to be able, in turn, to quickly adapt to these market requirements and manufacture high-quality products, while maintaining the lowest operating cost [6].

The reconfiguration manufacturing system (RMS) concept offers a solution to the challenge of rapidly and efficiently ramping-up volumes and varieties [7, 8]. Koren et al. [4] propose the first RMS definition as: “An RMS is designed at the outset for rapid change in structure, as well as in hardware and software components, in order to quickly adjust production capacity and functionality within a part family in response to sudden changes in the market or in regulatory requirements”. These authors also enumerate the key characteristics of RMS: modularity, integrality, customization, convertibility, and diagnosability.

Some more recent works about RMS discuss a) the prerequisites and barriers for developing RMSs and several RMS Design Frameworks [8]; b) the design and operational principles for RMSs [5]; c) the application areas and the key methodologies and tools for the RMS in Industry 4.0 [9]; and d) specific forms of RMS reconfiguration, focusing on reconfigurable layouts [6].

The appearance of new concepts and technologies related to Industry 4.0. [10] offers new opportunities and boosts RMS and modern manufacturing systems to enter a new era [5]. Nevertheless, although some recent works address the use of new technologies 4.0 in the field of RMS [9], there is still a significant lack of guides, methodologies, and tools for the immediate detection of deviations in manufacturing parameters and the automatic reconfiguration of manufacturing processes in real-time by using IoT, specifically, by integrating, in an interoperable environment the automated machining process, IA, IoT, sensors, Big Data and Data Analytics.

The business process “Machining process reconfiguration for Zero-Defect manufacturing” exposed by FACTOR, to address the manufacturing process reconfiguration, has as purpose to avoid machine stops that cause quality problems due to machine restarting, losses of productivity, and efficiency reduction. This will be achieved by early detection of possible problems using AI algorithms that forecast the future behavior of the machining process, changing the parameters that cause the problems; therefore, acting in the root of the poor behavior and the setback in the process.

The in-line control process begins once the machine has started production and the quality department checks the part and confirms that it is of good quality. From this moment on, possible production stops due to various events could begin to occur. These events could be related to the loss of quality of the parts, high level of vibrations, high temperature, tool breakage, tool wear, machine alarms, not good product visual appearance, metal chips status, or high-power machine consumption due to loss of tool efficiency and metal chip jams, amongst others.

When these events occur, the machine operator is who must find out the problem and then decide how to solve it. This process is long and expensive and runs the risk of not making the right decision due to a lack of data. Sometimes it causes breakages with a high economic value and, in every case, losses in quality, efficiency, and performance, the main parameters that influence the overall equipment effectiveness (OEE). In addition, none of the events’ occurrences are recorded, so no further study of the data resulting from these stops is made.

The information system currently available in the enterprise to prevent possible problems in production, the machine stops, or tool breakages is the CNC machine tool monitor system. Nevertheless, in the manufacturing process, CNC machine tools detect some of the problems encountered, but others must be detected by an operator, making early detection of problems and automatic reconfiguration impossible. Therefore, an interoperable information system is needed to collect the state of the machines and establish an early detection system based on the data analyzed.

To achieve FACTOR requirements, certain parts of the machine should be sensitized and all the data obtained should be processed for subsequent treatment and automated correction online. Thus, the main expectation when addressing the process reconfiguration problem is the development of an automatic and interoperable online data collection system and online correction of different machine parameters based on these online data, in order to make decisions about the reconfiguration of the manufacturing line. The reconfiguration of the manufacturing line is meant to be the actuation inside the manufacturing process, changing the independent variables that can influence in dependent variables, being the root of a future problem. The reconfiguration process should also be approached to maintain the dependent variables in the expected ranges due to the configuration of the independent variables.

The two main problems of FACTOR are related to forecasting quality problems in the production of parts and failures in the machines or tools to avoid breaks, to optimize the manufacturing process. More specifically FACTOR needs are:

- Check the health of the quality of the parts: the system should check if the measurements are within the quality ranges expected by the customer.
- Predict: The system should anticipate future problems and alert the operator with avoidance actions.
- Optimize the process: If there is not any potential issue to happen, the system should optimize the process.

3. i4Q manufacturing line reconfiguration toolkit

The Manufacturing Line Reconfiguration Toolkit ($i4Q^{LRT}$) is a collection of optimization micro-services that use simulation to evaluate different possible scenarios and propose changes in the configuration parameters of the manufacturing line to achieve improved quality targets. $i4Q^{LRT}$ artificial intelligence (AI) learning algorithms develop strategies for machine parameters calibration, line setup and line reconfiguration. The objective of the $i4Q^{LRT}$ is to increase productivity and reduce the efforts for manufacturing line reconfiguration through AI. $i4Q^{LRT}$ solution consists of a set of analytical components (e.g., optimization algorithms, machine learning models) to solve known optimization problems in the manufacturing process quality domain, finding the optimal configuration for the modules and parameters of the manufacturing line. Fine-tune the configuration parameters of machines along the line to improve quality standards or improve the manufacturing line set-up time are some examples of the problems that the $i4Q^{LRT}$ solves for manufacturing companies.

$i4Q^{LRT}$ solution will provide a fully interoperable and deployable service on either Linux or Windows servers, allowing it to be used by production managers in manufacturing companies in any industrial sector. Due to its interoperability, numerous data analysis services or digital twins can be connected to the solution to analyze all configuration parameters. In conclusion, this solution can obtain sensor data, apply optimization algorithms and provide optimized configuration parameters and actuation commands.

The AI services in the $i4Q^{LRT}$, are mainly optimization algorithms developed in Python. This solution comes with two characteristics: pre-trained models for use in specific industries and abstract models ready to be customized in a particular use case. Security, governance and manageability are delegated to external services through integrations using standard technologies (e.g. OAuth to manage user identity or the use of certificates). The solution will provide a software interface to integrate with the data via Application Programming Interface (APIs) or different messaging protocols.

3.1. FACTOR requirements for $i4Q^{LRT}$ solution

As we have seen above, FACTOR presents two main problems that seek to solve with the application of i4Q solutions. On the one hand, to avoid failures in the machines or tools. And, on the other hand, to prevent failures in the production of parts. Due to these two problems, the following needs (Ni) arise on the part of FACTOR:

- **N1**: Anticipate future issues regarding machine or tool breaks and lack of products' quality products.
- **N2**: Early warning that part defects are going to occur.
- **N3**: Find optimal parameters for the part production process.
- **N4**: Maintain optimum machining conditions.
- **N5**: Determine how to solve the process problem, when failure or event cannot be avoided.
- **N6**: Store data to keep a history of problems.

From these needs, a series of requirements (Ri) have been established by FACTOR, including:

- **R1**: Check the health of the quality of the parts
- **R2**: Collect data to generate failure patterns (part/machine/tool)
- **R3**: Store non-quality parts, failures and events

- **R4**: Analyse possible patterns of non-quality parts, failures, and events
- **R5**: Predict problem patterns via non-quality parts failures and events history
- **R6**: Warn operator and aid with a potential solution, when both non-quality parts and machine/tool breaks occur

In Table 1, a mapping between needs and requirements defined by FACTOR is depicted.

Table 1
FACTOR Needs vs. Requirements

	R1	R2	R3	R4	R5	R6
N1	X			X	X	
N2	X		X			
N3	X					
N4						X
N5						X
N6		X	X			X

Due to these needs and requirements defined by FACTOR, the $i4Q^{LRT}$ is presented as a solution where, by applying the appropriate model, it can be covered by the following functionalities (Fi):

- **F1**: Ability to collect data from different clients.
- **F2**: Ability to run live and analyse current data.
- **F3**: Ability to analyse live data, compare it with past data, and warn of potential problems.
- **F4**: The ability to deploy at the network's edge to provide rapid response.
- **F5**: Apply different optimisation algorithms on the same server and solve various planted problems.
- **F6**: Provide optimisation parameters of the production chain based on past data.

To check that the functionalities provided by the $i4Q^{LRT}$ fulfill the requirements defined by FACTOR, Table 2 is proposed.

Table 2
FACTOR Requirements vs. $i4Q^{LRT}$ functionalities

	R1	R2	R3	R4	R5	R6
F1		X			X	
F2	X		X	X		
F3	X			X		X
F4			X			
F5			X			X

4. Expected results measurement

The expected results that FACTOR aims to achieve with the implementation of $i4Q^{LRT}$ are: (i) to eliminate the parts that are manufactured with defects, rising the quality ratio; (ii) to eliminate machine stops, rising the time that the machine is producing final goods; (iii) to improve the Overall Equipment Effectiveness (OEE), which is computed through the product of quality ratio, the availability, and the effectiveness. To do that, a set of key performance indicators (KPIs) has been defined.

The efficiency of a manufacturing factory is measured by OEE, which is calculated through the product of quality ratio, availability, and efficiency (see table 3). The quality ratio is the relationship between the good quantity and the produced quantity. The quality ratio measures the number of good parts that have been produced without defects and are ready to be delivered over the total manufactured parts, which therein is an indicator of the waste that the manufacturer produces. Availability is a ratio that shows the relation between the actual production time, which Is the time that the machine has been producing, and the planned busy time for a work unit, which is the total time that the machine should have been producing. Effectiveness represents the relationship between the planned target cycle and the actual cycle expressed as the planned runtime per item multiplied by the produced quantity divided by the actual production time.

Table 3
KPIs definition to monitor i4Q^{LRT} results

OEE	quality ratio (QR) * availability (AVA) * effectiveness (EFF)
QR (%)	number of quality parts (GQ) / total produced quantity (PQ)
AVA	actual production time (APT) / Planned busy time (PBT)
EFF	(PRI * PQ)/ APT where PRI = Planned runtime per item

5. Conclusions

This paper is focused on the conceptualization of the Manufacturing Line Reconfiguration Toolkit (i4Q^{LRT}) as part of the solutions developed in i4Q project. i4Q^{LRT} comprises a collection of optimization micro-services that use simulation to evaluate different possible manufacturing processes and determine when the process parameters need to be reconfigured to prevent failures in the quality of product or process. This i4Q solution is being developed according to the requirements of FACTOR, a metal machining enterprise pilot that participates in the i4Q project. The use of this solution by FACTOR allows using all data obtained from sensors in the machines to anticipate future deviations in the manufacturing's parameters and to reconfigure online the process, reducing product-quality problems, waste and breakdowns in the machine tools. The main contributions of the paper are the identification of the process reconfiguration problem in a machining parts enterprise, the needs and solution requirements defined by FACTOR, the i4Q^{LRT} functionalities identification and description and, finally, the establishment of the needs-requirements-functionalities relations to the later development of a robust and useful solution. Future lines of research will consist of the full development of the i4Q^{LRT} solution, its implementation, and the evaluation of the results by means of the KPIs defined.

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