Title:
An Industry 4.0 Framework for the Quality Inspection in Gearboxes Production

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Keywords:
Industry 4.0, Knowledge Base, Machine Vision, Quality Control, Gearbox

DOI: 10.14733/cadconfP.2019.97-100

Introduction:
Nowadays, the development of Internet of Things (IoT) has been enhancing the factory digitalization with several advantages in terms of production, efficiency, product quality, and cost reduction [1]. This opportunity encourages the implementation of digital twins related to physical systems for monitoring and controlling the production workflow in continuous [4].

IoT is considered as an enabling technology for Industry 4.0, which is a term for describing the new revolution involving the digitalization of the smart factories in the world [7]. However, the paradigm of Industry 4.0 is still having some difficult to be spread developed in many industries [6]. The digital factories require the implementation of a digital twin [9] to replicate the physical system in a cyber one. The cost related to this transformation and the data management discourages the full implementation of IoT technologies in industry [7], especially for small and medium enterprises [5]. The digital twin is not only related to the production system but also to the quality check for the defects detection and analysis.

The production of gearbox parts, such as gears, hubs, shafts, and clutches, is a field where the quality checks are still based on manual operations [2]. Several studies are described in literature for measuring and checks the quality of gears, shafts, threaded parts, etc. However, the product characteristics such as the complexity geometry and the required accuracy, encourages the employed of manually operations. In fact, a completed clutch requires several checks. Up to 40 checks are estimated for a clutch part as reported in Fig. 1.

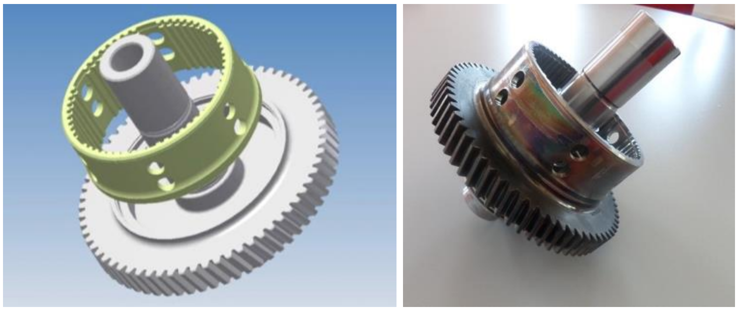

Fig. 1: Example of mechanical clutch for gearboxes.

Even if machine vision solutions have been already developed for this engineering field [8, 10], there is still a lack of automated applications for the completed and digitalized inspection of defects in the small-batches production of gearboxes. In fact, the orders of powertrain units for vehicles such as earthmoving machines, agriculture, and special vehicles, concern a niche market with high configuration and small-batches. The product configurations do not enhance the development of an automatic line for the quality check. The fragmentation and variability of this production is still considered as a limit for investing in Industry 4.0. The paper proposes an approach to overcome this limit enhancing the digital twin of the quality-check system.

Main Idea:
Firstly, the paper studies the enabling technologies for supporting the defect analysis in the context of Industry 4.0 for gearbox parts. Secondly, the approach aims to study the integration between the CAD geometry and the quality check process. A Knowledge-Based tool has been proposed to support the configurations of the quality control chain for a CAD geometry.

Fig.2 describes the proposed framework for defects analysis in the production of gearbox parts. The quality check regards different levels of fabrication. The quality checks start from the early production phases and end to the final assembling line. The checking systems concern 3D laser devices, smart cameras, and GO-NOGO gauges for thread, holes and shafts with tolerances, etc. Even if gauges are typically manual tools, the digitalization and automation of their report and analysis is necessary in order to implement the Industry 4.0 paradigm.

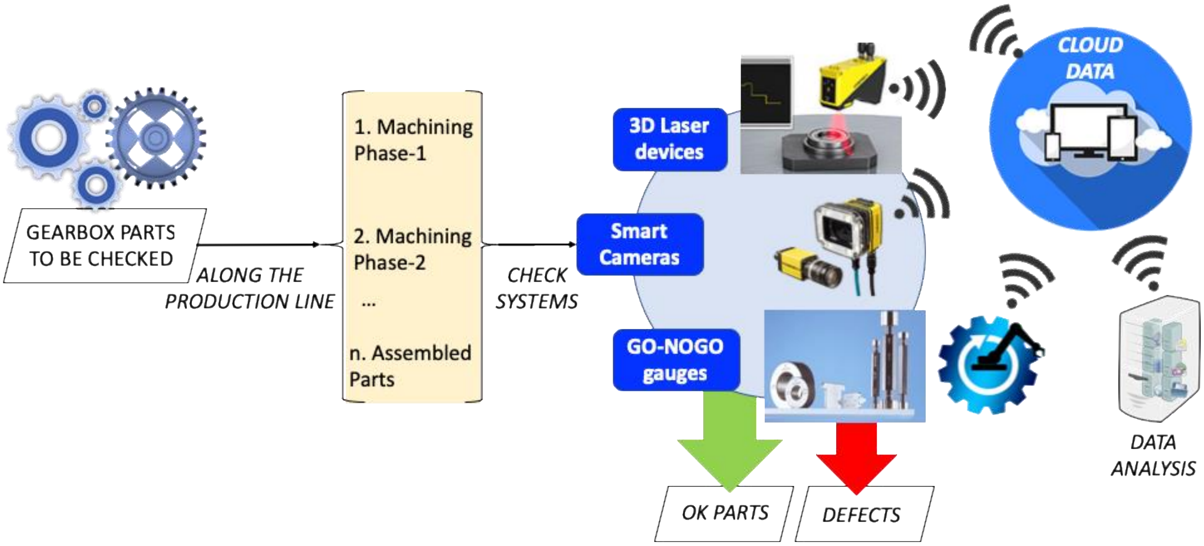

Fig. 2: Framework for the quality check of gearbox parts using inspection tools connected in cloud computing.

An automatic measurement system is proposed to evaluate the quality check, including the use of NO-NOGO gauge tools. Where 3D-laser measures are not suitable for the analysis, gauges can be employed using collaborative robots. These systems should be re-configurable in order to be applied in different product lines. Therefore, the paper also proposes a knowledge-based tool to support the configurations of the measurement system to be employed.

Fig. 3. describes the proposed methodology for assigning a quality checklist to a CAD model. The Knowledge Base regards the part recognition, the searching of geometrical entities to be checked using the PMI (Product Manufacturing Information) definition, and the assigning of a quality control (Q.C.) operation to each entity to be analyzed. Finally, the measurement system will be configured on the basis of the quality checklist. While the framework described in Fig. 2 concerns the first objective of the proposed research, the Knowledge-Based architecture reported in Fig. 3 completes the achievement of

the second objective. The interaction between the first and second objective allows an Industry 4.0 framework to be implemented for defects detection in the small-batches production of gearboxes.

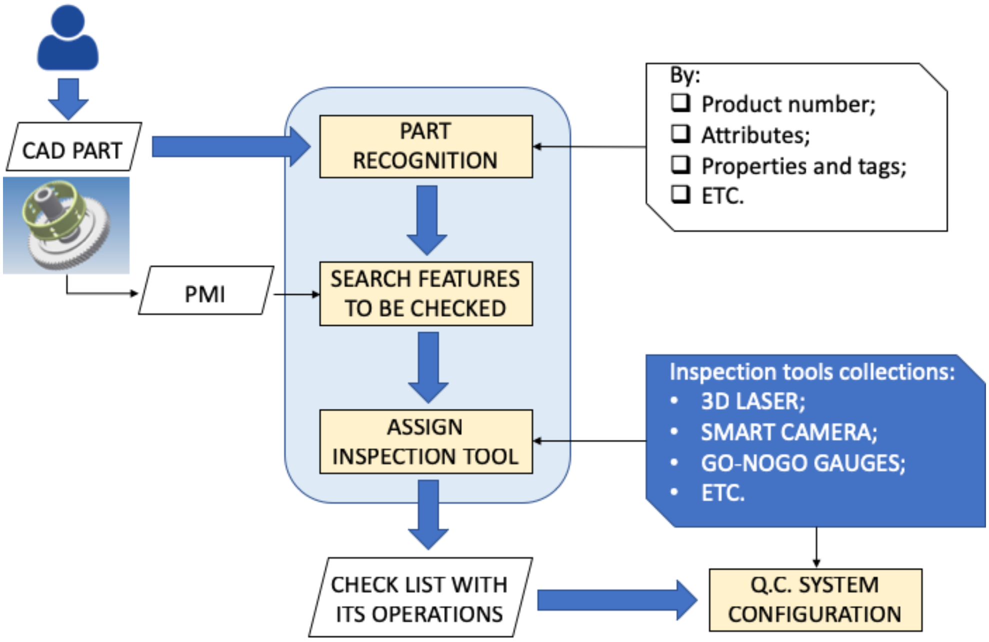

Fig. 3: The Knowledge-based approach for assigning a quality check-list to a CAD.

Test Case:
The application environment regards the context of transmission units for automotive, agricultural vehicles and earth-moving machines. The research is in collaboration with an Italian company involved in the power transmission sector. This company manages the entire production cycle, starting from the acquisition of raw material, fabrication (machining, heat treatments), quality control, and assembly up to final packaging. The majority of the production consists of oil bath clutches, toothed wheels, shafts, and gears. The all production is characterized by a great variability and small-medium batches.

The fragmentation of the production into hundreds of different product codes does not allow the application of classical automation systems, because this investment and implementation would not be compatible with the quantity to be produced. Therefore, in this context, the quality-control chain is a bottleneck. Here, the traditional quality checks regard the presence of all the processing steps (for example drilling, grinding, etc.), checking dimensional and geometric tolerances, evaluation of unacceptable burrs. Manual and semi-automatic quality controls are time-consuming. Following, a table for comparing traditional manually checks with an automation Q.C. line (Tab. 1). The comparison is based on the operation time for each task.

Operation	*Time – Manually [s]*	*Time – Automation [s]*	*Quantity*
Part handling	120	95	2
Hole presence	1	0,5	15
Diameter tolerance	5	15	4
Weldment Check	2	5	2
Writing report	60	0,5	1
Sending report	10	0,5	1

Tab. 1: An estimation of time consuming for manual and automated Q.C. tasks for a small clutch.

Table 1 shows an inspection planning for the model reported in Figure 7. The manually process is compared with the automated planning, which can be implemented into an Industry 4.0 context using sensors and connected robots. A process time has been evaluated and assigned for each operation. A quantity has been scheduled to each process in relation to the analyzed geometry.

Conclusions:

In the context of Industry 4.0, the paper deals with the development and integration of Internet of Things (IoT) in factory digitalization for the benefit of digital twin. In particular, the paper uses digital twin for quality control and detection of parts defect. The study is focused on a gear-boxes industry with a fragmentated production. In the proposed approach, the quality-control operations are defined and configurated by a Knowledge-Based which analyzes the geometry from the relative CAD model.
Using the proposed approach, about 60% of time reduction is estimated for quality-control operations. Therefore, in the context of quality control, the smart factory solutions can be applied with benefits also in the case of a fragmentated production, which is generally a limit for the Industry 4.0 implementation.

The full paper also describes the enabling technologies to be involved for the digitalization of the inspection checks. Laser scanners and smart camera are suitable technologies to be involved in this process. On the other hand, checks with GO-NOGO gauges can be more difficult to be managed. The use of collaborative robots can be an early solution to improve these inspection digitalizing both control and decision.

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