Inspection Strategies and Defect Prediction Models for quality control in low-volume productions

Abstract

This Doctoral Dissertation set out to plan quality inspection strategies by adopting suitable defects generation models and by assessing inspection performances in low-volume productions. The Dissertation offers some essential insights into the field of quality control for low-volume productions, where the limited historical data available and the difficulty of implementing traditional techniques and methodologies make the inspection process planning extremely challenging. The following Research Questions (RQs) are specifically addressed throughout the Dissertation:

RQ1: Can defects occurring in low-volume production processes be predicted using probabilistic models?

RQ2: How to evaluate the performances of quality inspections in low-volume productions?

RQ3: How to support designers in the early design phases of inspection process planning of low-volume productions?

In order to answer the aforementioned RQs, the Dissertation has been structured in six chapters, as described below.

A general introduction of the framework of the research and the importance of the topic is provided in Chapter 1, as well as the purpose statement and the research design and methods used in the current Dissertation.

Chapter 2 is concerned with an overview of the quality inspections in manufacturing processes. A considerable amount of literature has been published on inspection procedures in the manufacturing field. This chapter investigates the bibliography related to the inspection procedures from different perspectives. The specific aim is to review recent studies on inspection procedures and highlight research areas that are not adequately covered by the literature for identifying new challenges and research perspectives.

The identification of reliable and suitable prediction models of defects occurring in the final product is key to plan quality inspections, especially for low-volume production due to the scarcity of historical data. The different typology of inspection requires a different structure and conceptual paradigm of the models. With the purpose of identifying reliable and suitable models of defect predictions and answering the first research question - RQ1, Chapter 3 begins by laying out a review of defect modeling in manufacturing in Section 3.1, and by proposing an overview of the current studies related to the application of machine learning for product quality control and improvement in Section 3.2. Then, a distinction between models to predict defects for in-process and offline inspections, respectively in Sections 3.3 and 3.4, is proposed. In detail, Section 3.3 introduces some defect prediction models designed for assembly processes, with a specific focus on the close relationship between assembly complexity and defect rates. In Section 3.4, a model specifically designed for offline inspections is proposed, using Additive Manufacturing as a case study.

The second research question - RQ2 - is addressed in Chapter 4, where the formulation of two useful indicators for assessing inspection strategy performance is proposed. In detail, to derive these indicators, the inspection strategy is modeled separately for in-process inspections and offline inspections, respectively, in Section 4.1 and 4.2. In such modeling, the defect prediction models proposed in Chapter 2 are combined with other inspection variables, including inspection errors and costs, with the purpose of assessing the performances of the two categories of inspection strategies through a pair of indicators. The first indicator provides an assessment of inspection effectiveness, evaluated based on undetected defects remaining in the final product. The second indicator is obtained by carrying out an overall economic evaluation of the strategy adopted. These indicators are formulated following a different architecture

depending on their use for evaluating in-process or offline inspections. The probabilistic models formulated are strongly influenced by the cause-effect relationships between the process and inspection variables. In order to take this aspect into account, Section 4.2 extends previous studies in the field of in-process inspections, that are reviewed in Section 4.1, by including possible interactions between process and offline inspection variables, in terms of cause-and-effect relationships. The final section of Chapter 4 introduces a preliminary uncertainty evaluation of the two performance indicators.

Intending to support designers in the selection of the most suitable inspection strategy, Chapter 5 is conceived to answer the last research question - RQ3 – by proposing an operational tool, called Inspection Strategy Map (ISM). The ISM has the dual purpose of analyzing and guide the inspection planning process. The description of such a tool is provided in Section 5.1, while different applications of the proposed approach are finally described in Section 5.2. The case studies addressed belongs to different manufacturing sectors, specifically regarding assembly processes for in-process inspections and Additive Manufacturing technique for offline inspection.

The concluding chapter summarizes the original contributions of the Dissertation, focusing on the benefits, limitations and possible future developments.