Explainability of Quality Issues in Manufacturing: a Semantic Based Approach

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Abstract

This paper presents an approach using stream reasoning for detecting manufacturing quality losses. To semantically detect quality issues situations, an ontology-based context for manufacturing is introduced. Moreover, as heterogeneous data streams have to be integrated, a combination of existing models using stream processing and offline reasoning can be used. This combination allows continuous processing of data and the use of expert knowledge to detect anomalies and provide explanations to operators and stakeholders. An illustrative case study about quality assurance succeeded in detecting anomalies and proposing an explanation.

Keywords

Quality Assurance and Industry 4.0 (Quality 4.0), Ontology, Explainability, Quality issues detection

1. Introduction

With the advent of Industry 4.0 and the ability to monitor production lines in real time, new possibilities in terms of product quality management have emerged. One of them is Quality 4.0 [1], an extension of Industry 4.0 to quality assurance which allows to combine quality data with data from other sources (machine sensors, manufacturing, etc). As industries need to reduce risks and costs and ensure the quality of products, predictive models can use data collected by machine sensors to anticipate breakdowns or manufacturing errors. However, these models are not all inherently explainable and can entail huge difficulties in tracking root causes of anomalies [2].

This work is part of the XQuality [1] project whose main goal is to implement intelligent and automated quality assurance to assist operators in manufacturing companies. We propose to use a hybrid approach to detect and explain quality loss by reasoning over an ontology that integrates all the available knowledge such as results of predictive models, technical documentation and expert knowledge.

2. Quality issues detection and explanation

Quality assurance in manufacturing companies is an essential process for ensuring that products meet standards. It contributes to customer satisfaction and reduces the costs of defects. To tackle quality issues, we propose to adapt the approach presented in [3]. The idea is to detect situations that may lead to quality losses by observing products and tracking abnormal sensor values. Expert knowledge will allow the identification and assessment of the root cause that led to a detected abnormal situation.

The framework proposed in Figure 1 is based on [3]. Three modules are used to detect and explain quality issue situations reasoning over an ontology: **Translation**, **Temporal Relations** and **Cause Determination**. This reasoning is performed in real time (stream reasoning) or offline (classical reasoning over an ontology).

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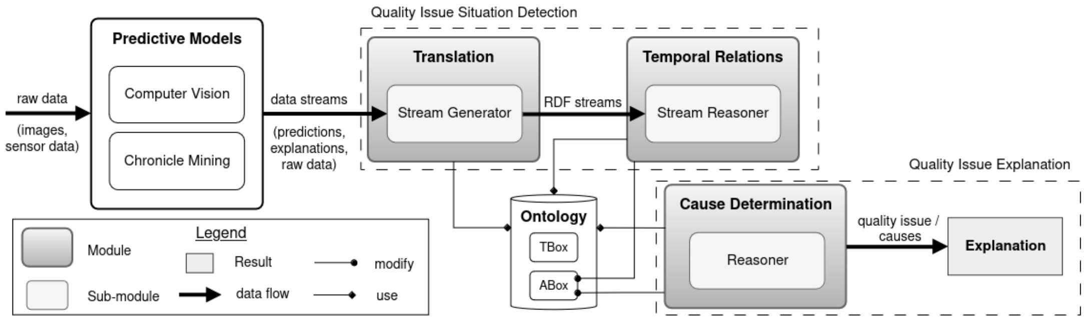

Figure 1: Proposed framework for quality issue detection with stream reasoning.

To detect quality issues, an ontology based on the *Context Ontology* described in [4] is used. This ontology is composed of three core ontologies (*Sensor Ontology*, *Time Ontology*, *Location Ontology* and *Situation Ontology*) and three domain ontologies (*Resource Ontology* and *Process Ontology*). Therefore, we propose to extend the *Situation Ontology* with a *Quality Assurance Ontology*. As the *Situation Ontology* concerns only situations on machines, we want to extend it with quality issues situation detection on products. The *Quality Assurance Ontology* is based on TOVE Traceability Ontology [5] which provides representation to identify and trace a quality problem. As TOVE is a core ontology, we mainly use the idea of traceability between products and activities. This allows to link products to the machine that produced or modified them when and where the default occurred.

The **Translation** module is responsible for collecting sensor data and converting it to RDF streams thanks to *Stream Generators*. This component performs a semantic enrichment of raw data using the concepts and relations defined in the ontology. One *Stream Generator* is used per sensor.

The **Temporal Relations** module is used to explore the data. RDF streams are continuously queried into the *Stream Reasoner* using the ontology to contextualize the streams. The queries represent different quality issue situations to detect. For this component, we used RSP4J [6] to query the streaming data. The data from the detected situations is then formatted and put into the ontology.

The **Cause Determination** module identifies the root cause and explains the problem. The *Reasoner* is used over the ontology to check the consistency of the ontology and then, infer new knowledge. The cause of the quality problem can then be determined using different classifiers as proposed in [7].

3. Illustrative case study

In this section, we present an illustrative case study created to test our framework. We consider a manufacturing production line named `PL1` composed of two machines $\mathtt{M}_1$ and $\mathtt{M}_2$ which produce products named $\mathtt{P}_1$, $\mathtt{P}_2$ and $\mathtt{P}_3$. The production line is equipped with sensors that observe machine and product properties. The sensors collect data on properties in Table 1. Constraints ranging from c_1 to c_8 relate to machines and the other ones relate to products.

Set of constraints C							
ID	Properties	Restriction	Device	ID	Properties	Restriction	Device
c_1	Motor temp.	> 500°C	$\mathtt{M}_1\mathtt{mt}_1$	c_7	Roller speed	> 600 mpm	$\mathtt{M}_2\mathtt{R}_1$
c_2	Punching speed	> 2000 times/min	$\mathtt{M}_1\mathtt{p}_1$	c_8	Cooling temp.	> 25°C	$\mathtt{M}_2\mathtt{T}_1$
c_3	Punching pressure	> 8 MPa	$\mathtt{M}_1\mathtt{p}_1$	c_9	Porosity	> 10 pu	Pr
c_4	Environment temp.	< 25°C	$\mathtt{PL}_1$	c_{10}	Porosity	> 40 pu	Pr
c_5	Roller temp.	> 1300°C	$\mathtt{M}_2\mathtt{R}_1$	c_{11}	Roughness	> 0.3 μm	Pr
c_6	Roller pressure	> 450 bar	$\mathtt{M}_2\mathtt{R}_1$	c_{12}	Flatness	> 27 I-Units	Pr

Table 1
Constraints definition

Set of situations S		
Sit.	Constraint(T)	Description
s_1	c_2, c_3	$\mathtt{M}_1\mathtt{t}_1$ Tool wear
s_2	c_3, c_4	$\mathtt{M}_1\mathtt{p}_1$ Press Wear
s_3	c_1, c_2, c_3, c_4	$\mathtt{M}_1$ Machine Wear
s_4	c_6, c_7	$\mathtt{M}_2$ Machine Wear and Tear
s_4	c_5, c_8	$\mathtt{M}_2$ Fluid leakage
s_5	c_5, c_6, c_7, c_8	$\mathtt{M}_2$ Mechanical failures

Table 2
Situations and their concerned constraints

Set of quality situations S_q		
Sit.	Constraint(T)	Description
s_{q1}	c_4	$\mathtt{P}_1$ water spot
s_{q2}	c_{12}, c_2, c_3	$\mathtt{P}_1$ punching defects
s_{q3}	c_{11}, c_{12}, c_2, c_3	$\mathtt{P}_1$ punching defects
s_{q3}	c_9, c_4, c_5, c_6	$\mathtt{P}_2$ uneven deformations
s_{q4}	$c_9, c_{10}, c_4, c_5, c_6, c_7$	$\mathtt{P}_3$ surface defects

Table 3
Quality issues situations and their concerned constraints

Abnormal situations that could lead to machine failures are defined from expert knowledge and expressed as a set of constraints in Table 2. Quality issues situations are also defined from expert knowledge and expressed as a set of constraints in Table 3. They describe quality issues detected on products and the associated machine and product constraints.

Data streams are then created by the *Stream Generator* and continuous queries are performed on them. To do this, the *Stream Reasoner* is used with an ontology containing information on the production line. Once a situation is detected, is it added to the ontology. An off-line reasoning is done to check the consistency of the ontology. Another *Reasoner* is then used to provide an explanation thanks to the information contained in the ontology which allows to link defects found with expert information and technical documentation.

4. Conclusion and future work

A semantic approach to quality loss explanation in the manufacturing industry is presented. Data streams are processed with stream reasoning allowing real-time situation detection. A context ontology is used to help detect quality issues by enriching the information contained in the streams. In future work, explanations of abnormal situations and their causes will be adapted according to the end user.

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