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Interoperability: linking design and tolerancing with metrology

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Abstract

On October 30, 2014 the American National Standards Institute (ANSI) approved QIF v 2.0 (Quality Information Framework, version 2.0) as an American National Standard. Subsequently in early 2016 QIF version 2.1 was approved. This paper describes how the QIF standard models the information necessary for quality workflow across the full metrology enterprise. After a brief description of the XML 'language' used in the standard, the paper reports on how the standard enables information exchange among four major activities in the metrology enterprise (product definition; measurement planning; measurement execution; and the analysis and reporting of the quality data).

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1. Introduction

Metrology has – at times – been placed in the role of quality checking, the final step of conformance testing before a product is deemed acceptable. The more advanced manufacturer of components realizes that there is more value in metrology than a simple final-acceptance check. Using metrology information to improve the manufacturing process by controlling and reducing product variability has become an integral part of modern, high-quality manufacturing. The management of variability is more easily performed in organizations that are integrated vertically because different parts of the process 'belong' to the same company. In a flatter, more distributed, manufacturing environment this task is much harder, as each participant (company, division, etc.) may optimize their part of the process to the detriment of the complete process's quality. Standardization is recognized as a means to allow interoperability across a variety of platforms in almost countless contexts, from standardized reporting of gasoline octane content based on underlying test methods to the height of work surfaces, including office desks and commercial kitchen counters. The specific focus of this paper is Product and Manufacturing Information (PMI) for discrete products.

The goal of the Quality Information Framework (QIF) [1,2] is to support the transfer of information and data related to metrology through the entire product process, from design to manufacture to the archival and analysis of data related to the products. This paper will provide a high-level overview of the current QIF structure and the various components of this structure. We will then focus on one particular area (i.e., metrology resources) in more detail, both to examine the thinking behind the development of this area and to reveal how we envision end users realizing the benefits of the QIF. We will conclude with some specific attributes of the metrology resources structure that relate to large scale and portable metrology systems.

Acronyms

QIF	Quality Information Framework
XML	Extensible Markup Language
PMI	Product and Manufacturing Information

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2. The Quality Information Framework (QIF)

The QIF captures the natural structure of information flow related to part geometry: from the initial description of the geometry and the supplemental information that is provided by the designer all the way to the statistical analysis of inspection results for multiple workpieces. At each step along the way, the necessary information is captured in a standard format, allowing greater flexibility in choosing the tools used in the next process step. The standard format is defined using Extensible Markup Language (XML) and demonstrated using a variety of tools that support the QIF standard [3].

2.1. XML schemas and files

XML is readable by both humans and computers. The same file that is used for modeling a particular situation can also be examined by a person looking for particular information. This is similar to the use of HTML for web pages. The two main types of files that we will consider are XML Schema Definitions, herein schemas, and XML files. The QIF consists of schemas, which define templates for the type of information needed in each step. When QIF is used, an XML file is generated, which could be evaluated to see if the file conforms to the schema. The file fragments below show a simple example of the relationship between the schema definition and an instance of a particular use of the schema.

Table 1. XML schema and XML file example.

```
<xs: element name="Contact">
  <xs: ComplexType>
     <xs: sequence>
       <xs: element name="name" type="xs:string"/>
       <xs: element name="FamilyName" type="xs:string"/>
       <xs: element name="Address" type="xs:string"/>
     </xs: sequence>
  </xs: ComplexType>
</xs: element>
```

Fragment of an XML schema definition

```
<Contact>
    <name>Ed</name>
    <FamilyName>Morse</FamilyName>
    <Address>UNC Charlotte</Address>
</Contact>
```

Resulting XML file instance

In Table 1, the schema defines what information is needed (i.e., it's a template), and the user puts the appropriate information in an instance XML file. Many XML files could be created that conform to the schema template.

2.2. The QIF schemas

The QIF schemas are used at the conclusion of each step in the product-quality process so that the data passed to the next step has a standard format. For example, when the design of the part geometry and tolerances is concluded, it may be transferred to metrology in a native format, or in another standard format such as ISO 10303-202 Managed Model-based 3D Design, known as STEP AP242 [4]. It may also be exported according to the QIF MBD (model-based definition) schema. This ensures automated processes that determine measurement requirements, based on the part geometry and tolerances, have access to the information needed to complete this task. Note that as in the above example, the schema doesn't describe the geometry – simply how the geometry is captured in the file. The other QIF application schemas used are QIF Resources, QIF Rules, QIF Plans, QIF Results, and QIF Statistics. The execution of measurement programs within the QIF uses DMIS version 5.2 [5]. These application schemas rely on common elements that are captured in the QIF libraries, as shown in Fig. 1.

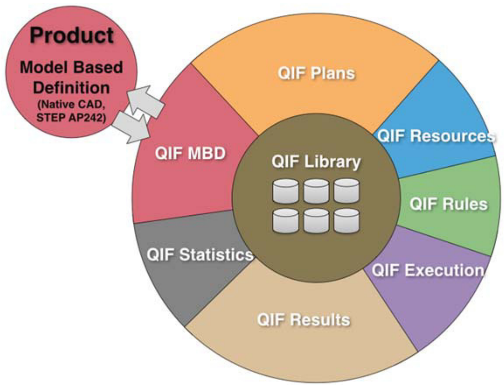

Fig. 1. A representation of the QIF schemas and the supporting libraries

The role of these data models is apparent when we think about the quality process: given the part geometry and tolerances, what is needed to develop a measurement plan? The identification of the part attributes that must be measured is determined by the quality requirements and by the manufacturing processes used. This information is captured in the "whats" portion of the QIF Plans schema. Once it is known what must be inspected, the information about available metrology resources (QIF Resources) and rules for applying these resources (QIF Rules) must be applied to complete the "hows" portion of the QIF Plans. Now the measurement plan is complete, this is implemented using DMIS and the results are captured in accordance with the QIF Results schema. Finally, post processing can be accomplished according to the QIF Statistics schema. As a reminder to the reader, each of these schemas simply provides a template for moving information. Fig. 2 shows the alignment of the various schema definitions to the different tasks in the metrology lifecycle.

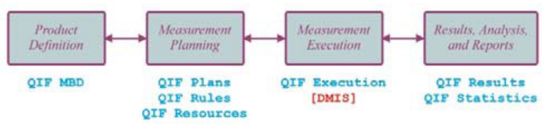

Fig. 2. The parts of QIF related to the overall metrology workflow

3. Metrology Resources

In this section, recent work in the area of QIF Resources is described. Constructing a template that will have a logical space for the important attributes of common metrology instruments is desired in developing a schema for metrology resources. One long-term objective in the development of a comprehensive QIF Resources schema is the ability to capture a metrology company's entire instrument catalog within the template. Similarly, a manufacturing organization could have information about all of their instruments stored in this same format. This would enable different software to browse through the inventory to determine what instruments are most appropriate for various measuring tasks, which instruments will soon be in need of calibration, and other automated tasks.

3.1. Structure

The structure of the metrology resources schema is a hierarchy of instruments and sensors, each containing descriptive attributes of these resources.

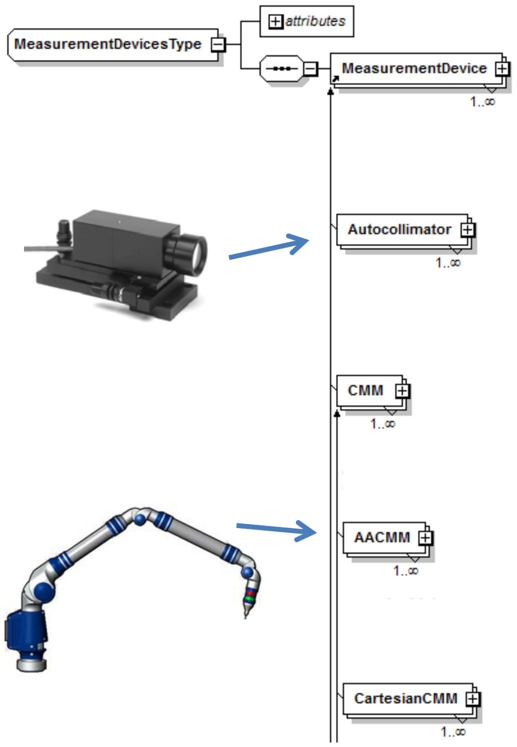

Fig. 3. Part of the Measurement Resources hierarchy

The highest level of this hierarchy is Measurement Resources, followed by the next level containing the subtypes of Version information, Fixtures, Tools, Detachable Sensors, and Measurement Devices. Part of the measurement devices hierarchy from QIF version 2.1 is shown in Fig. 3. This figure shows how both an Autocollimator and CMM are modeled as resources, and the CMM has multiple subtypes below the main CMM type.

3.2. CMM-specific attributes

The CartesianCMM type shown in Fig. 3 contains attribute information that is relevant to these instruments. Specific examples of these attributes include: the home location of the CMM, the maximum permitted workpiece mass, the motion speeds (both DCC and joystick), machine accuracy, and others. A data model that supports this level of detail is useful when selecting a piece of measuring equipment and developing the measuring plan for the equipment.

The CMM type is an extension of the base type of `UniversalDeviceType`, which in turn is an extension of the `MeasurementDeviceType`. This is important because common attributes to all non-manual measuring devices that have a measuring volume can be captured in the Universal device type. This prevents these attributes from being repeated at many places through out the schema definition. For example, different types of measuring volumes are described for "universal devices," including a Cartesian (box shaped) volume, a spherical volume, and a cylindrical volume. An explicit geometric model of the measuring volume can be defined if the volume does not have one of these shapes, such as when the usable measuring volume is reduced by a tool-changing rack.

4. Building Trust and Traceability

Now that the structure of QIF and some details of the data model have been explained, the method of determining the validity of data shared using this model is described. Ensuring complete data integration of both data trust and traceability is important to manufacturing industries. Those organizations must be able to determine data declarations, who did what to the data, when they did it, and potentially why it was done. Both regulated and non-regulated industries need effective and efficient processes for data trust and traceability. Regulated industries (e.g., aerospace, automotive, medical) focus significant resources on data trust and traceability to ensure they comply with the appropriate public-safety oversight. Manufacturers in both regulated and non-regulated industries care about data trust and traceability to reduce product-liability exposure in their supply chains and the public.

Ouertani *et al* [6] suggest the following questions must be answered to support data trust and traceability:

- What product knowledge is created or represented?
- Who are the actors playing different roles in creating, using, or modifying product knowledge?
- Where is the product knowledge created and located?
- How is the product knowledge being created or modified?
- Why was certain product knowledge created or modified?
- When was the product knowledge created or modified?

QIF version 2.1 supports the ability to embed digital signatures using Private Key Infrastructure methodology from the X.509 standard [7]. QIF version 2.1 introduces two elements to the schema – (1) a `signature` block and (2) a set of elements for traceability. The `signature` block allows the user to add the *who* and *when* to the QIF document. The traceability elements allow the user to add the *what* to the QIF document. Using the `signature` block and traceability elements together enables full traceability of who did what to the QIF data and when it was done. This traceability supports the end-user's ability to determine if the data in the QIF document may be trusted.

5. QIF Benefits to the Product Lifecycle

Standardized metrology data across the product lifecycle, and tasks, such as measurement planning, can be automated is the benefit of QIF. Any software that can read part files in the QIF MBD format, as well as the QIF Resources and QIF Rules files for the organization, could generate measurement plans and send them to measuring equipment using the QIF Plans schema.

As described in Section 2.2, QIF's concept of identifying a metrology "catalog" both of resources and rules combined in a plan brings a significant benefit to the product lifecycle. Knowing what resources are available to an organization and knowing the metrology rules that constrain the inspection capabilities for a given part enables the organization to determine if upstream (e.g., design, manufacturing) decisions comply with metrology's needs. QIF's inherent structure supports efficient and effective knowledge capture of metrology capabilities. This knowledge could be leveraged to determine if a design or manufacturing decision being made will detrimentally affect the inspection process. This would reduce waste and cost significantly.

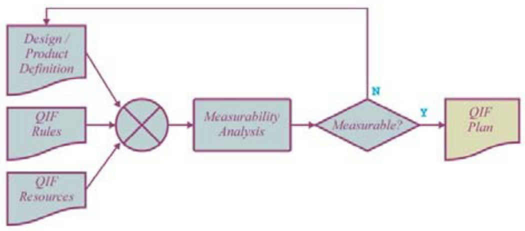

Fig. 4. Process flow for analyzing measurability using QIF

For example, a design engineer could follow the example process flow shown in Fig. 4 to determine if the product definition is complete and measureable. The engineer would collectively examine the product definition, pre-defined QIF rules, and the catalog of metrology resources represented in QIF resources. The engineer would then complete an analysis prior to releasing the design to fabrication to ensure the product could be inspected using the pre-defined metrology rules and available resources. If the product is measureable, a QIF plan would be the output. If the product is not measureable, the engineer would make changes to the product definition until the product becomes measureable. The result is a design that complies with metrology's needs such that the information and production definition is in a state that metrology can effectively and efficiently use for completing the inspection process. Using a "Design for Inspection" approach built around QIF ensures that the product definition is correct at release and eliminates the need to iterate the handoff of the product definition between design and supply chain. This reduces the time wasted by rework, while also reducing production costs due to missing information not being discovered until after the product has been fabricated.

6. Conclusion

This paper presented an overview of the QIF standard, a more in-depth discussion of the QIF Resources schema definition, a discussion of trust and traceability issues and their support in QIF documents, and an example of the type of application development that can be enabled when QIF is used to capture the metrology information throughout the product-design workflow. As the standard matures, and more commercial software support the reading and writing of QIF-compliant files, the goal of a *digital thread* [8] linking all aspects of the product lifecycle will come closer to reality. This powerful set of standards, describing data models for all of the metrology-related aspects of the product process flow, is already instrumental in providing new opportunities for the management of metrology across a variety of platforms.

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