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An information model for surface metrology

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Abstract

According to ISO standards, the specification and verification of surface texture includes an ordered set of operations. In order to reduce the specification uncertainty, it is of importance to model the significant information related to surface measurement. This paper documents the development of a XML-based information model for surface metrology. Traditional paper-based documents with unstructured data are intergraded into one structured data for surface metrology. Therefore, it limits the specification uncertainty and enhances the reproducibility of surface measurement.

Keywords: surface texture; information model; XML; specification uncertainty;

1. Introduction

To measure is to compare. In order to compare the measurements undertaken at a different time or location, it is of importance to store and exchange the information related to a measurement. The lack of such information has been quantified by the term of uncertainty, such as specification uncertainty [1], and definition uncertainty [2]. To manage such uncertainties, ISO/TC 213 has improved the technique language used by the designers, production engineers and metrologists, namely Geometrical Production Specifications and verification (GPS).

Surface metrology is the science of measurement of surface texture, the scale-limited feature of a surface (i.e. roughness and waviness). There are two types of information for a surface texture measurement: 1) the measured dataset which records the dimensional information as a digital representation of a measurand in certain condition produced at a certain phase of a measurement; 2) the characteristic and the measurement conditions which state the key information of a measurand. There are various file formats used to store the measured dataset in a computer. However, the information of the characteristics and the measurement conditions is spread in many graphic/text-based documents, such as user-input, ISO documents, instrument guides, national measurement guides, etc. So an engineer faces a problem: how to organise/manage such information? The more the detailed information is, the less the definitional uncertainty. At the same time, too much information could make it difficult to exchange of information. In the pre-information age, all our information was held on paper. Today most of it is held electronically either as digital documents, or as data in databases. The use of computers makes storing and exchanging more detailed information possible, thereby reduces the related uncertainty. This is especially important for surface measurement due to the complexity and variety of surface metrology.

In the specification of surface texture, the most often used model is through the technical drawings. This graphic-based method efficiently integrates various geometrical requirements in one technical document.

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With the developing in Compute-Aid Design (CAD), the traditional paper-based drawings are normally undertaken with aid of computer and store in digital form. Models have developed to use text-based language to represent the graphic-based symbols. For example, most of the CAD/CAM systems support ISO 10303 - STandard for the Exchange of Product model data (STEP) to represent and exchange product manufacturing information. Danner et al. proposed a STEP-Based information model for dimensional inspection [3]. These models aim to integrate all produce information within its life-cycle. Thus they only provide limit information of the specification of surface texture.

In the verification of surface texture, there are various data file formats available. However, most of them focus on the storage of measured data with little information about the measurement condition. Muralikrishnan and Raja proposed a common format for exchanging surface texture data across different platform, which is a XML-based container for the information of part, measurement, data file, analysis, process and function [4]. Another file format with lot of detailed measurement information is the SMD file format. SMD is defined as the protocol for software calibration in ISO 5436-2 [5].

There is a logical relationship between specification and verification [6]. Models discussed above mainly focus on one part. The shape and size of such information are changed from the designers to the metrologists. It could contribute the uncertainty in communication level. Thus, it is of importance to develop an information model to standardise the message from the specification to verification and vice versa.

To this end, this paper develops an information model to manage the measurement information for surface metrology. The output of this research is an XML based markup language, namely Surface Texture Markup Language (STML). The methodology of this project is detailed in section 2. Section 3 documents the design and development of this model. An example is given in section 4, and section 5 is the conclusion.

2. Methodology

2.1. The information modelling process

An information model is a representation of concepts, relationships, constraint, rules, and operations to specify a data semantics for a chosen domain of discourse [7]. An information model described here centres on providing the sharable, stable, and organised structure of information requirements in the field of surface metrology. This model provides a container to the description of the measurand and measured value of surface texture measurement.

There are various practices to develop an information model. The underlying methodologies for the recent modelling practices are based on three approaches:

1. The entity-relationship approach: An entity-relationship model is an abstract and conceptual representation of structure data, which depicts data in terms of the entities and relationships described in the data. Its building blocks are entities, relationships, and attributes.
2. The functional modelling approach: It is a structured representation of the functions, behaviours, activities or processes within a modelled system. It uses objects and functions over objects as the basis, and it often uses data-flow diagrams.
3. The objected-oriented approach: The fundamental construct of this approach is the object, which incorporates both data structures and functions. Its building blocks are object classes, attributes, operations, and associations.

These approaches view the data with different emphasises. The entity-relationship approach lacks the preciseness in supporting the detailed level. The functional modelling approach is often used in the development of a certain software application. The objected-oriented approach considers both the data and the function, which has the advantage to describe the measurand and measured of surface texture measurements. Wang pointed out the disadvantages of these approaches to present GPS information in a database, and introduced the category approach in the design and development of knowledge-based GPS systems [8]. Currently, it is still under development in the academic domain. This project, therefore, will use an objected-oriented approach to model the message due to it more widely used in industry.

Many information modelling languages, in graphical form or texture form, have been developed. They provide various ways to formally represent an information model. This project has used XML schemas to express the constraints on the structures and contents of the message.

NIST has developed an information modelling process, which includes three phases: 1) to develop the definitions of the scope of the model's applicability; 2) to collect information requirements; and 3) to develop the model [7]. This modelling process has implemented in this project.

2.2. XML and XML Schema

Extensible Markup Language (XML) is a set of rules for encoding documents in a computer-readable form. It is defined in the XML 1.0 specification [9] recommended by the W3C . This open standard produced standardises the format of an XML document and specifies the behaviour of XML processing software. A XML document is made up a tree of elements with a short specification. To develop an XML processing software implementation, thus, is relative easy. And many free implementations exist. These implementations can be employed in the creation of STML processing software, making it simple to read and write STML documents.

A XML Schema is a description of a type of XML document. It is expressed in terms of constraints on the structure and content of that type of XML documents.

3. The development of STML

3.1. Scope of STML

In this context, a message is the vessel for containing specification and verification information of surface texture, which provides the description of the object intended to produce and verify. The messages are built based on the following ISO standard documents:

- Fundamental ISO standard document in metrology: the VIM3 [2] and the GUM [10].
- GPS Language developed by ISO TC/213: Key standard documents are ISO 17450 [6] [1], ISO 14253 [11] [12].
- ISO standard documents for surface texture measurement: At current stage, this project focuses on the ISO 4287 [13] parameters. The related standard documents are ISO 3274 [14] , ISO 4288 [15], ISO 11562 [16] etc.

This project focuses on the consistentce of the message from the metrology point of view. It does not cover how the description is mapped to an actual software implementation. Some parallel projects [8, 17] have developed the data model for storing the messages in a database, and an expert system to produce them.

3.2. Collecting the information requirements

To collect the information requirements, this project used two methods: 1) literature survey and standards survey; 2) industrial data reviews.

3.2.1. Developing the information model

3.2.1.1. Indication and its sub-elements

Currently, an often used mechanism to express the requirements of surface texture is through the drawing indication in the technical documents. The indication defined (e.g. see Fig. 1) in ISO 1302 [18] is widely accepted. STML uses it as the key reference to produce and interpret a message. An indication of the surface texture requirements specifies the following information:

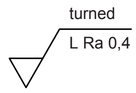

Fig. 1 The indication of surface texture

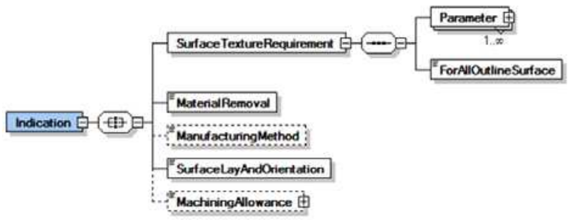

Fig. 2 Diagram of schema for surface texture indications

manufacturing method, filtering bandwidth, tolerance, parameter and the surface lay.

The keyword <Indication> is the XML element or tag representing the drawing indication of surface texture with its hierarchical composition of lower levels of information (see Fig. 2). The sub-elements of the <Indication> are the <MaterialRemoval>, <ManufacturingMethod>, <SurfaceLayAndOrientation>, <MachiningAllowance> and <SurfaceTextureRequirement> tags. The first four elements are of importance to develop its manufacturing operator. A certain pattern is produced by a certain process. So it is also useful in the prediction of the future performance of this component.

The <SurfaceTextureRequirement> tag encapsulates all related information of the surface texture requirements. Its sub-elements consist of a <ForAllOutlineSurface> element and one/several <Parameter> elements. The <ForAllOutlineSurface> tag specifies whether the surface texture requirements are for all surfaces represented by the outline of a workpiece. The surface texture requirements on an engineered surface are expressed by one or several parameters. Each parameter is a quantity intended to be measured (i.e. each parameter defined a measurand). An indication, therefore, defines one or several measurand(s).

According to ISO 1302 [18], each of the <Parameter> elements should specify the following information: specification limit type, filter type, transmission band, parameter name, evaluation length, specification limit interpretation and parameter value. They are defined as new datatype, namely “ParameterType”, marked up with corresponding tags as shown in Fig. 3. So, a graphic-based drawing indicating is mapped into a text-based XML document.

The indication specifies both the manufacturing requirements and the surface texture requirements on an engineering surface. They are the basis on where the manufacturing operator and the specification operators are produced. We do not discuss the manufacturing operator here due to it beyond the scope of this project. The next section will use the indicated information to form the specification operator.

3.2.2. Measurand and its sub-elements

The measurand is defined as the result of the specification operator, which is an ordered set of operations [1, 6]. So, the keyword <Measurand> is the XML element representing the measurand. Its sub-elements are the <Partition>, <Extraction>, <Filtration> and <Evaluation> tags. The contents of the indication are mapped into this structure with some rename labels as shown is Fig 4.

Obviously, this specification operator is incomplete and a further callout is required. ISO 1302 [18] listed 17 related ISO standard documents. They have been used to develop the sub-elements of each operation.

The <Partition> tag specifies the operation used to identify bounded feature(s). In the case of surface profile texture parameters, it includes two sub-operations: 1) partition of a non-ideal surface from the skin model, and 2) partition of non-ideal lines from the non-ideal surface. The key reference of this operation is ISO 4288 [15], which provides the rule for selecting the areas to be inspected for homogenous surface and inhomogeneous surface.

The <Extraction> tag specifies the operation for extracting the feature. Only one nominal stylus instrument is specified in ISO document, namely ISO 3274 [14]. So the default values given in ISO 3274 [14] are called out if they are not specified. The sub-elements of the <Extraction> tag include maximum sampling spacing, maximum tip radius, measuring force, and max measuring speed (see Fig. 5).

The tag of <FOperator> specifies the F-Operator, which is the process to remove the nominal form in the measuring data. In technical drawings, F-Operator does not need to be indicated due to form (error) is not a component of surface texture [18]. However, F-Operator is often undertaken in surface measurement practice. So F-Operator should be stated if necessary. F-Operator utilise same or similar techniques in the filtration operation (F-Operator is named as the form filter in some publications). Moreover, the output of extraction operation is surface texture and form. Thus, the F-operator is grouped into the extraction operation.

To balance the information, some of the information does not detail in this model, due to the following considerations:

- Extraction operation does not need to specify the measuring environment because a measurand model is free from environment effects according to the VIM3.

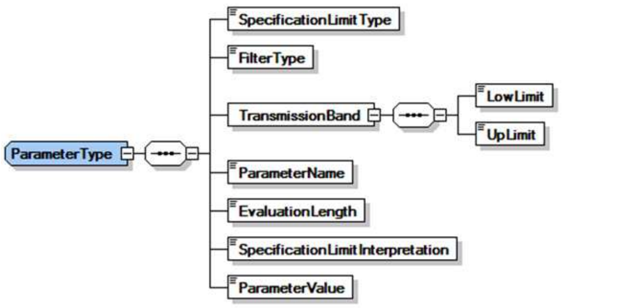

Fig. 3 Diagram of a surface texture parameter according to its drawing indication

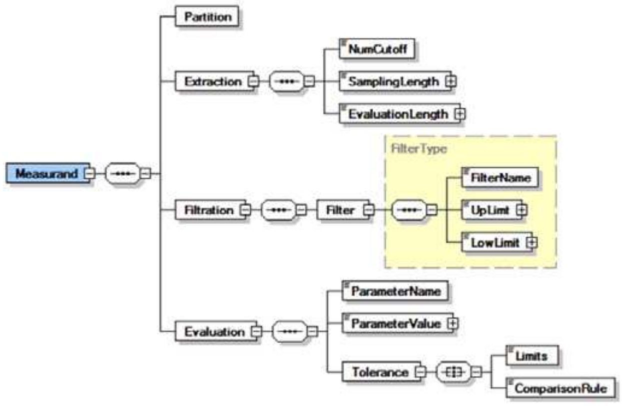

Fig. 4 Diagram of a measurand according to the drawing indication

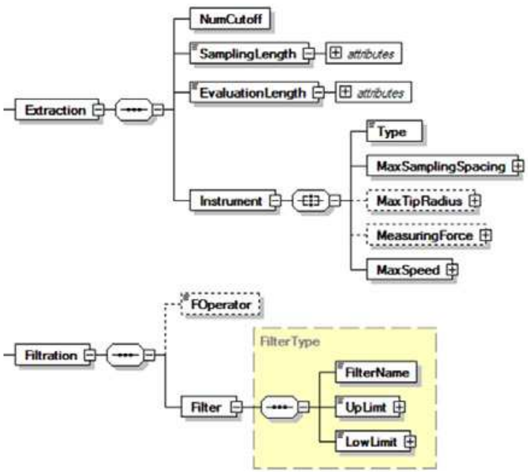

Fig. 5 Extension of the extraction operation of a specification operator

- Filtration operation and evaluation operation does not need to detail the algorithms. Compared with the variation in extraction operation, their variations are relatively insignificant. (However, this variation needs to be assessed by the calibration with the aid of softgauges.)

Then, the specification operator is formed in STML based on the current GPS language.

3.2.3. Measured value and its sub-elements

3.2.3.1. Developing the perfect verification operator

A perfect verification operator is built based on a perfect instrument within a perfect environment [1]. A metrologist often faces two situations: 1) a measurand with specification; 2) a measurand without a specification. In the first situation, a perfect verification operator will be formed by mapping the element from the complete specification operator (see Fig. 6). In the second situation, she/he will develop a metrology solution based on her/his knowledge of surface metrology and results obtained from measurement. A perfect verification operator can be produced based on the metrology solution.

According to the duality principle [1], a specification operator and its corresponding verification operators consist of duplicated operations in the same order. The differences of two operators are input and output of them. The input of the specification operator is the skin model, while that of the perfect verification operator is an actual workpiece. Their outputs are "measurand" and "measured values" separately. As the result of a perfect operator, the "measured value" described here should be the "true value" of the measurement. The true value is unknown, so "reference value" and "nominal value" could be used as the true value [2].

- According to the VIM3 [2] , the "reference value" is used as the "true value" of a measurement. This situation is often met when a metrologist calibrates an instrument by measurement standards. He/she interprets the measurement conditions according to the requirements of the standards.
- In a certain application, the reference value may not be available. The "nominal value" can be used as the "reference value". This situation often occurs when an engineer assesses a workpiece. He/she interprets the measurement conditions according to a technical drawing or a previous measurement report.

3.2.3.2. Developing actual verification operator

Based on the perfect verification operator, an actual verification operator is developed. The actual verification operator describes the measurement condition within in a certain laboratory or workshop. The sub-elements of <Partition> may include the <Replica> to specify the using of replica of the assessed surface. There are more sub-elements of the <Extraction> tag as showed in Fig. 7.

Note that the <SamplingSpacing>, <TipRadius> and <MeasurementSpeed> tags record actual value of the measurements, while their corresponding tags in the

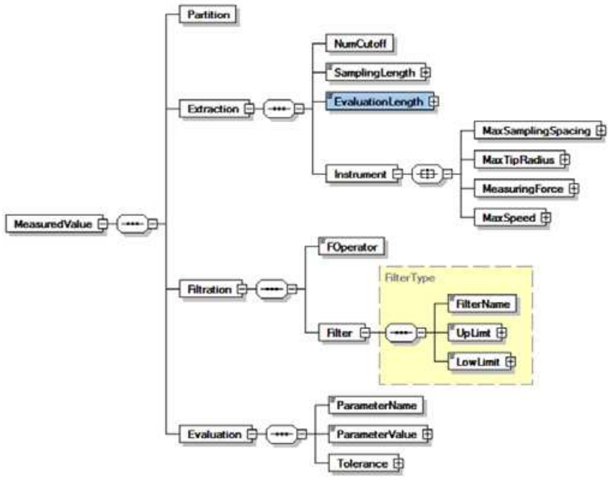

Fig. 6 Diagram of a perfect verification operator

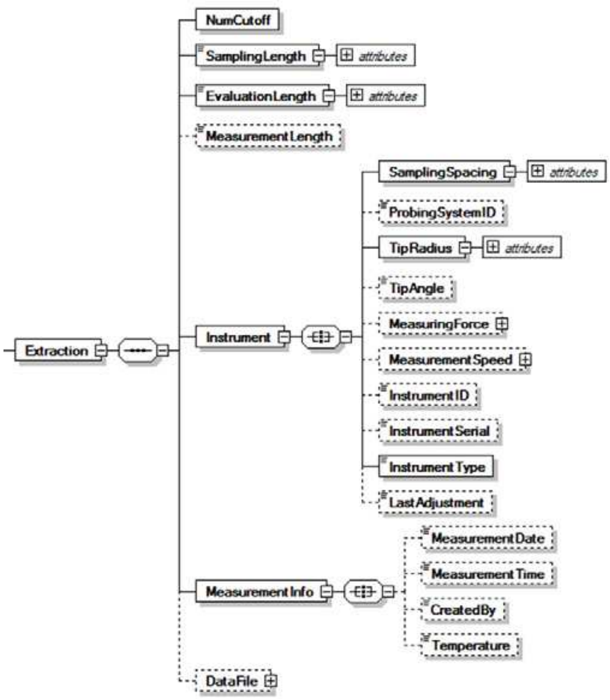

Fig. 7 Diagram of the extraction operation of an actual verification operator

perfect verification operator only specify their maximum values.

An implementation of a default filter [16] has an end effect [19]. So the <EndEffect> and <MeasurementLength> tags are introduced to record the handling method, and the corresponding changing on the actual measurement length.

In addition, more tags can be developed to address various application requirements. For example: more detailed information for the actual instrument such as tip angle, skid, instrument id and so on; data file information such as location of file, file name, axis information, etc. (Note that the measuring data point information does not recommend storing in this file).

Then, an actual verification operator is formed in STML.

3.2.4. Validation of message

The validation of a message should take consideration on the following parts:

- Constriction and rule: Many constrictions and rules have been stated in ISO standard documents. It sets the relationship between some contents, for example, the ratio of the filter λs and the filter filter λc. It can be validated by an expert system.
- Syntax: The message should follow the STML's syntax. It can be validated by the XML Schemas developed as follows.

XML Schema is another standard that allows the definition of a full specification for a XML document. The messages in STML states the location of the Schema (in the form of a URL address of this project web site), which is used to validate this file. This web site is also provided detailed interpretation of each tag to avoid the ambiguity and to make the document traceable.

4. A case study: Euromet Project 600

Euromet Project 600 - comparison of surface roughness standards, is the most recently inter-comparison between 17 NMIs in Europe. The travelling of standards and measurements took two years (May 2001 to May 2003), and a 578 page final report was released via BIPM website in May 2004. Parts of this report will be used as a case study. This comparison has used 7 surface texture measurement standards. The type D1 hardgauge 663g are used in this case study.

4.1. Defined measurand

The measurand is defined in the Appendix A3 of the report [20]. Eight parameters are required to be measure for the hardgauge 633g. Thus, it is defined eight measurands, and one of them (parameter Ra), expressed in STML form, is listed below.

4.1.1. Example of defined measurand in STML

```
<Measurand
xmlns="http://www.surfacetext.info/Schemas/SpecificationOperator"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.surfacetext.info/Schemas/Specificati
onOperator L:\Projects\STML\FullSpecificationOperator.xsd">
  <Partition>According to the measuring plan of Type D defined in
ISO 12179</Partition>
  <Extraction>
    <NumCutoff>5</NumCutoff>
    <SamplingLength Unit="mm">0.8</SamplingLength>
    <EvaluationLength Unit="mm">4</EvaluationLength>
    <Instrument>
      <Type>Stylus</Type>
        <MaxTipRadius Unit="um">2</MaxTipRadius>
        <MaxSpeed Unit="mm/s">0.5</MaxSpeed>
        <MeasuringForce Unit="mN">1</MeasuringForce>
      <MaxSamplingSpacing Unit="um">0.5</MaxSamplingSpacing>
    </Instrument>
  </Extraction>
  <Filtration>
    <Filter>
      <FilterName>Gauss</FilterName>
        <UpLimt Unit="mm">0.8</UpLimt>
        <LowLimit Unit="um">2.5</LowLimit>
      </Filter>
  </Filtration>
  <Evaluation>
    <ParameterName>Ra</ParameterName>
    <ParameterValue Unit="um">1.5</ParameterValue>
  </Evaluation>
</Measurand>
```

4.2. Measured values

The measured values is reported in Appendix B1 of the report [20]. Two of them, expressed in STML, are listed as follows.

4.2.1. Example 1 of measured values in STML

```
<?xml version="1.0" encoding="UTF-8"?>
<MeasuredValue
xmlns="http://www.surfacetext.info/Schemas/SpecificationOperator"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.surfacetext.info/Schemas/Specificati
onOperator L:\Projects\STML\AcutualVerificationOperator.xsd">
  <Partition>According to the measuring plan of Type D defined in
ISO 12179</Partition>
  <Extraction>
    <NumCutoff>5</NumCutoff>
    <SamplingLength Unit="mm">0.8</SamplingLength>
    <EvaluationLength Unit="mm">4</EvaluationLength>
    <Instrument>
      <SamplingSpacing Unit="um">0.2</SamplingSpacing>
      <TipRadius Unit="um">2</TipRadius>
      <MeasuringForce Unit="mN">1</MeasuringForce>
      <MeasurementSpeed Unit="mm/s">0.1</MeasurementSpeed>
      <InstrumentID>Taylor Hobson Nanostep1</InstrumentID>
      <InstrumentType>Stylus</InstrumentType>
    </Instrument>
    <MeasurementInfo/>
  </Extraction>
  <Filtration>
    <Filter>
      <FilterName>Gauss</FilterName>
      <UpLimt>0.8</UpLimt>
      <LowLimit>2.5</LowLimit>
      <EndEffect/>
      <SoftwareID>PTB</SoftwareID>
    </Filter>
  </Filtration>
  <Evaluation>
    <ParameterName>Ra</ParameterName>
    <ParameterValue Unit="um">1.520</ParameterValue>
    <Uncertainty>
      <Value Unit="nm">46</Value>
      <CoverageFactor>2</CoverageFactor>
      <DegreesofFreedom/>
```

```
   </Uncertainty>
  </Evaluation>
</MeasuredValue>
```

4.2.2. Example 2 of measured values in STML

```
<?xml version="1.0" encoding="UTF-8"?>
<MeasuredValue
xmlns="http://www.surfacetext.info/Schemas/SpecificationOperator"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.surfacetext.info/Schemas/SpecificationOperator L:\Projects\STML\AcutualVerificationOperator.xsd">
  <Partition>According to the measuring plan of Type D defined in ISO 12179</Partition>
  <Extraction>
   <NumCutoff>5</NumCutoff>
   <SamplingLength Unit="mm">0.8</SamplingLength>
   <EvaluationLength Unit="mm">4</EvaluationLength>
   <Instrument>
    <SamplingSpacing/>
    <TipRadius Unit="um">2</TipRadius>
    <InstrumentType>Stylus</InstrumentType>
    <InstrumentID>Talysurf 6</InstrumentID>
    <MeasuringForce Unit="mN">1</MeasuringForce>
    <MeasurementSpeed Unit="mm/s">1</MeasurementSpeed>
   </Instrument>
   <MeasurementInfo/>
  </Extraction>
  <Filtration>
   <Filter>
    <FilterName>Gauss</FilterName>
    <UpLimt Unit="mm">0.8</UpLimt>
    <LowLimit Unit="um">2.5</LowLimit>
    <EndEffect/>
    <SoftwareID>TalyProfile 3.0.8</SoftwareID>
   </Filter>
  </Filtration>
  <Evaluation>
   <ParameterName>Ra</ParameterName>
   <ParameterValue Unit="nm">1525</ParameterValue>
   <Uncertainty>
    <Value Unit="nm">24</Value>
    <CoverageFactor>2</CoverageFactor>
    <DegreesofFreedom/>
   </Uncertainty>
  </Evaluation>
</MeasuredValue>
```

4.3. Discussion

Thus, a traditional report is transformed into STML. The unstructured data, therefore, map into structure data which are arranged by operators and operations according to GPS. Each XML file specifies its XML Schema file name (e.g. FullSpecificationOperator.xsd) and location (e.g. "http://www.surfacetext.info/Schemas/SpecificationOperator") which used to validate it. The Schema file is stored in this project website, which also provides the detailed definition for each tag. It makes this document traceable and reduces the possible misunderstanding.

In addition, many XML related techniques make the use of STML easily. Many available XML editors can be used to create the STML file. Using XSLT (Extensible Stylesheet Language Transformations) , STML can be easily mapped into another XML data file or a report (in PDF or Word format and so on).

5. Conclusion and future work

This paper has presented the development of a XML-based information model for specification and verification of surface texture. Traditional paper-based documents with unstructured data are integrated into one structured data format for surface metrology. The structure of this model is adhered to the latest GPS. Examples have given.

In the future, the information model requires more related components, such as the XSLT components for transforming the SMD file, other XML formats into STML and vice versa. A continuous update to stay in current is also needed.

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