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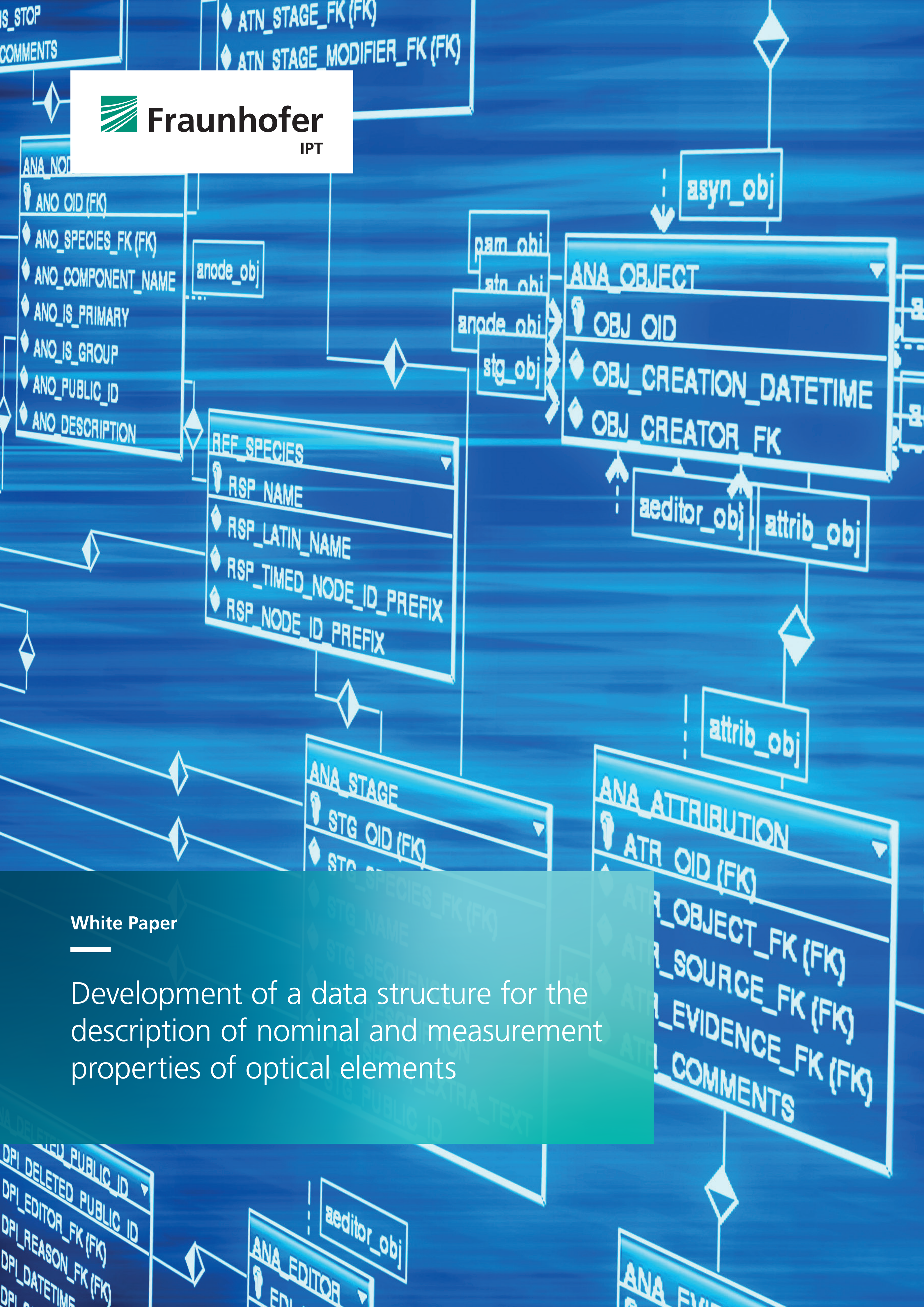

White Paper

Development of a data structure for the description of nominal and measurement properties of optical elements

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Introduction

Recent advances in the digitalization of production processes allow a thorough analysis of the different process parameters. Machine learning algorithms help to find the different dependencies of the production parameters by modelling the production processes especially when a large number of parameters is involved. The knowledge gained of the dependencies of the production parameters can be used to greatly improve the production quality. To harness the full potential of this approach, the different production processes along a value chain must be considered as a whole instead of modelling every process independently. Especially in the field of optics production with tight production tolerances, that are often at the edge of today's manufacturability and metrology, the approach of considering all production processes as a whole holds great potential. The evaluation of the production parameters of the whole value chain can help predict and improve the quality of the final product, using techniques such as tolerance matching or enabling adaptive changes in the process without compromising the quality of the final product.

The quality requirements for optical elements and optical systems especially in the field of precision optics for space, medical technology and automotive are constantly increasing. The only way that those requirements can continue to be met by the manufacturers while maintaining production costs at the same level and even improving production time and efficiency is when all acquired information along the production chain is available to all parties involved. This means, that all necessary information regarding each intermediate product must be easily accessible for each company or even department involved in the production process. In order to achieve that, all associated partners need to speak the same "language" to make the information exchange barrier-free. Currently, this requirement is by no means met. Crucial product information is shared via all types of different data formats, this circumstance can lead to time loss for conversion of data into the right format, information loss and extra work to generate data that originally already existed. This holds especially true for the process of metrology within the production process. Different metrological systems produce different measurement values in different data formats. For an efficient integration of the metrology to the digitalization framework, common data formats are crucial since this allows metrology manufacturers to directly integrate these data formats into their metrology systems and users of the metrology systems to integrate measurement data into the digitalization framework in a standardized way.

In this paper, a data structure for the complete description of single optical elements like spheric and aspheric lenses is proposed. The data structure contains the nominal parameters and tolerances of the lens according to ISO standard 10110 as well as their measured counterparts.

The results presented in this paper were gathered within the project "EverPro" publicly funded by the European Regional Development Fund (ERDF).

Development of the data structure

The starting point for the development of the data structure was ISO standard 10110 [1] which regulates the preparation of drawings for optical elements and systems. The ISO standard 10110 states which quantities should be provided in the technical drawing of an optical element and in which way, in order to improve manufacturing processes and quality control. The following properties of optical elements according to ISO standard 10110 were considered within the developed data structure:

- surface form (e.g., A, B, C, RMSt, RMSi, RMSa) [2]
- centering (e.g., tilt, lateral displacement) [3]
- surface imperfections (e.g., scratch, dig) [4]
- surface texture (e.g., roughness, area roughness) [5]
- surface coating (e.g., transmittance, reflectance, absorption) [6]
- aspheric surfaces (e.g., standard coefficients, Forbes QCON) [7]

The above-mentioned properties must be represented by the data structure in a logical and comprehensible composition. Therefore, a hierarchical description with different layers of abstraction of the optical element was developed with help of methods of object-oriented programming. In object-oriented programming, real-world objects like optical elements can be described with classes containing attributes that describe the properties of the object. The attributes might be classes themselves containing again a set of attributes. This can be used to describe more complex properties of an optical element like its surface coating. Different levels of abstraction are used to describe a variety of optical elements. Lenses, mirrors, diffractive optics, and prisms are all optical elements that share certain attributes: They all have a part name, a part number, a name of the manufacturer or a date of manufacturing just to mention a few. On the other side, they all have very different shapes and functions that cannot be described with a common subset of attributes. To describe objects with common and different attributes, object-oriented programming uses a concept called inheritance. With inheritance, new objects can be derived from other objects sharing the attribute from the object they are derived from and having new attributes at the same time.

The developed data structure for the description of an optical element is depicted in Figure 1 using a UML class diagram [8]. The names of the classes and attributes are chosen to have a clearly understandable meaning using camelCase. In the highest level of abstraction (Level 1), the optical element is described as an abstract object called OpticalElement with the attribute information describing the meta information of the optical element (partName, partNumber and supplierName). OpticalElement can have multiple expressions. It might be a mirror, a lens or even a diffractive optical element. However, within this paper we only consider lenses. Therefore, the next level of abstraction (Level 2) is the class Lens. Lens inherits from OpticalElement. Its attributes centerThickness, edgeThickness, diameter, surface1 and surface2 describe the geometrical shape of the lens. The attribute material describes properties related to the lens material that are clustered within the Material class. The attributes surface1 and surface2 are instances of the class Surface that holds attributes describing the functional surfaces of the lens. The Surface class has the attributes diameter, clearAperture, coating, imperfection, roughness, areaRoughness, waviness and mathematicalModel of the nominal surface shape. Depending on the mathematical model which can either describe a plane, spheric or aspheric surface, a deeper level of abstraction is introduced (Level 3). The reason behind this is that a different subset of attributes is needed for the description surfaces of each mathematical model. The Plano surface needs no attributes for the description of its shape. Only attributes describing its deviation from the nominal shape are needed (PV and RMS). Furthermore, its centering towards a defined axis (wedge angle) is documented within the attribute centring. In addition to the attributes of the Plano surface, the Spherical surface has the attribute radius and a set of attributes describing its deviation from the nominal shape in more detail. These attributes are the PV values A, B and C and the RMS values RMSt, RMSi and RMSa according to ISO 10110. Furthermore, the Zernike expansion to a desired order can be described (zernikeCoefficients). In addition to the attributes of the Spherical extension of the Surface class, the Aspheric extension contains the coefficients of the aspheric surface model (including the conic constant and the parameter h in case the Forbes QCON description of the asphere is used). It also contains the attribute sagTable and a more detailed version of the centering class to account for double sided aspheric lenses. This is because double sided aspheric lenses need two parameters to describe the centering of one surface to the other, which are tilt and lateral displacement.

In general, all the described attributes of the different layers of abstraction are classes themselves to account for all the parameters that are related to the respective property. For reasons of simplicity, all attributes that can be described with one numerical value as nominal value are following the same pattern that is described in a class called NominalMeasurementProperties. The diameter, centerThickness, radius or clearAperture are some of the attributes described within this class. The class has the attribute nominal represented by the class Nominal containing the nominal value (float) its unit (string) and its nominal tolerance (float) as symmetric interval around the nominal value. The attribute measurement of NominalMeasurementProperties represented by the class Measurement contains the measurement value (float), its unit (string) and the measurement uncertainty (float) as symmetric interval around the measurement value. Some of the properties cannot be described by the class NominalMeasurementProperties alone but make use of this class (e.g., SurfaceTexture). The full description of the classes and their respective attributes can be found within the UML class diagram.

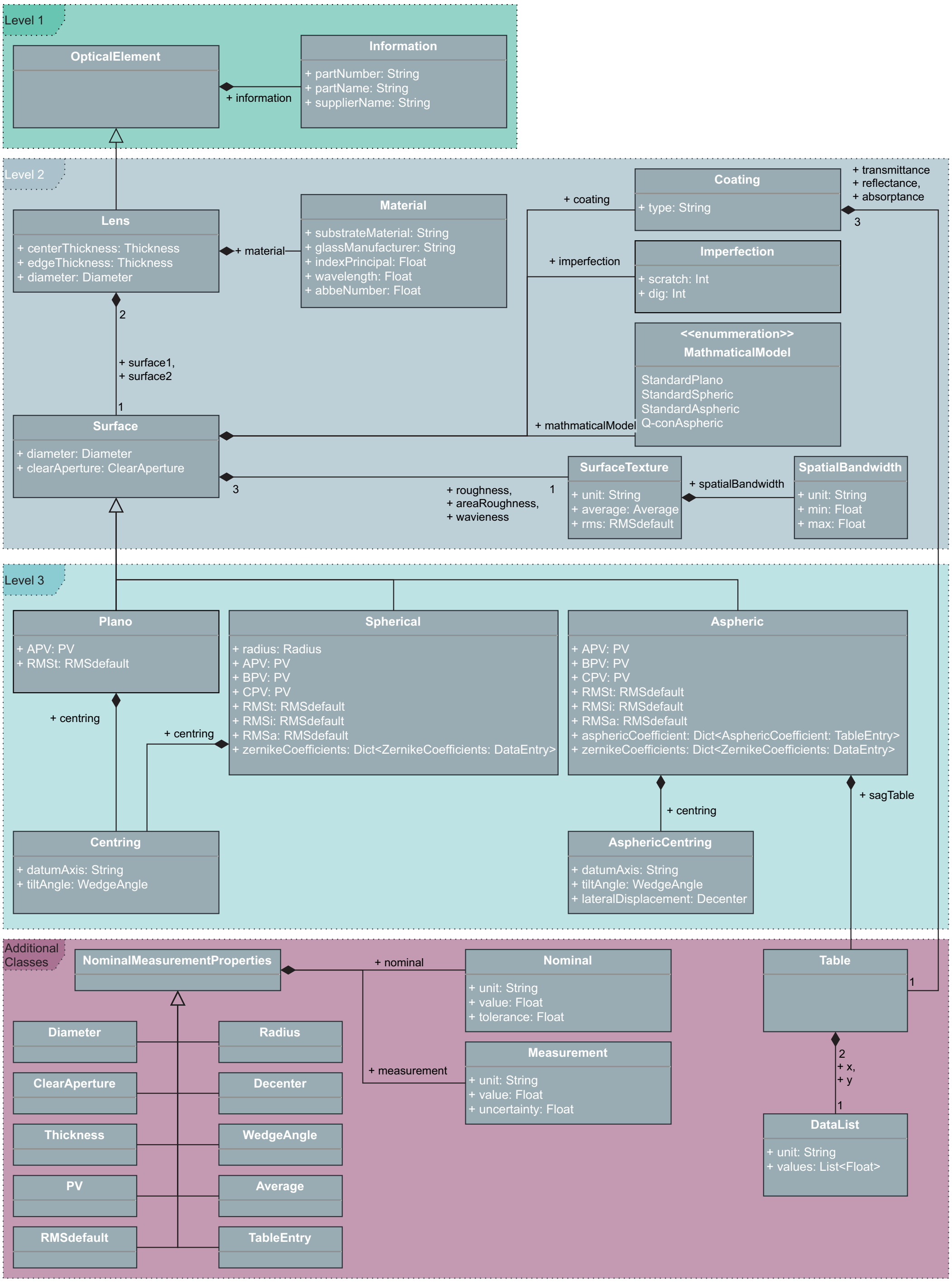


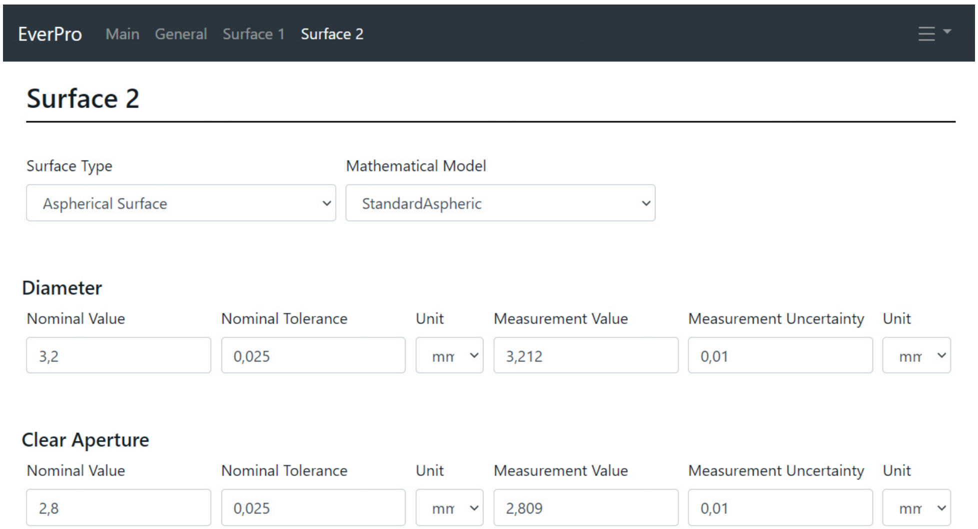
Figure 1: UML class diagram of the data structure for the description of nominal and measurement properties of optical elements.

Implementation in JSON and integration into a production infrastructure

The data structure was implemented in JSON (JavaScript Object Notation). JSON is an open standard file and data interchange format that uses human-readable text to store and transmit data objects [9]. The data objects consist of attribute-value pairs and arrays making JSON viable for storing a hierarchical data structure as the one developed within “EverPro”.

The creation of the JSON file was done with the help of a Python Script. Within the creation, the nominal data of the lens described were automatically stored within the file. Further development aims to develop interfaces to common interfaces to common optics design software like Zemax Optic Studio or Code V so that the nominal data can be transferred automatically to the JSON file making the process more efficient and preventing manual input errors. Within the project “EverPro” lens surface form measurement data is generated with the help of a tactile surface measurement system and a Fizeau interferometer. Additionally, transmitted wavefront data are acquired with a Shack-Hartmann wavefront sensor. The generated measurement data is exported from the proprietary measurement software in open file formats like *.xml or *.txt. The measurement data are parsed through a Python script from the open file formats and written in the JSON file describing the specific measurement properties of the optical element. The JSON file is imported into a database. The database also stores the production parameters of the manufacturing process of the optical elements. The production parameters and the measurement results can be used for further data analysis to optimize the production process.

We developed a web-based application for data visualization and input of additional measurement data using React Bootstrap (Figure 2). The application can read and write JSON data from local or database sources. The application has three data tabs. In the general tab, metadata like part name and number are shown. Furthermore, the tab shows general geometry parameters like center and edge thickness and material parameters. The remaining two tabs contain parameters describing surface 1 and 2 respectively. Besides the parameters describing the nominal shape and the measured shape deviation of the respective surface according to the specific mathematical surface model (plano, spheric, aspheric), the tabs contain centering information, surface imperfections, surface texture and surface coating. The web-based application is ready to transfer measurement data from one production site to another connected to the database via a secure VPN connection.



Surface 2

Surface Type: Aspherical Surface

Mathematical Model: StandardAspheric

Diameter

Nominal Value	Nominal Tolerance	Unit	Measurement Value	Measurement Uncertainty	Unit
3,2	0,025	mm	3,212	0,01	mm

Clear Aperture

Nominal Value	Nominal Tolerance	Unit	Measurement Value	Measurement Uncertainty	Unit
2,8	0,025	mm	2,809	0,01	mm

Figure 2: Web-based application for input and visualization of nominal and measurement properties of optical elements. The data is stored in JSON format as a file or directly within a database.

Conclusion

We demonstrated the development and implementation of a data structure for the description of nominal and measurement properties of optical elements. The main focus of the data structure is the description of rotationally symmetric lenses. The data structure has a modular design using methods of object-oriented programming so that the addition of other types of optical elements like mirrors or prisms can be implemented easily. Furthermore, the data structure was implemented in JSON format and used within a database containing production parameters of the manufacturing of aspherical lenses. In context of Industry 4.0 the data structure is a key component for the implementation of a digital twin of optical elements. This digital representation enables data-driven optimization of production processes, e.g. improvement of the product quality by adaptive assembly and tolerance matching, prediction of product quality, and product tracking over the whole supply chain. Although the developed data structure is ready to be used within production processes, a standardization of the data structure should be pursued in form of e.g. an ISO standard. Standardization would benefit the comprehensive application of the data structure within the optics industry. Measurement data export in standardized JSON file format could then be implemented directly into the measurement software by metrology companies. Manufacturers of optics production machinery could also implement the data structure to ensure seamless integration of new processes within the optics manufacturing chain and drive forward digitalization within the optics industry.

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