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WHITEPAPER

DIGITIZED ASSEMBLY OF COMPLEX OPTICAL SYSTEMS

CHALLENGES IN AUTOMATED PRECISION OPTICS ASSEMBLY

The production of newly developed optical systems often requires new, particularly precise assembly processes. The development of such processes involves high risks, is time-consuming and requires extensive expert knowledge. The miniaturization of components and systems in particular, which are subject to ever-tighter manufacturing tolerances, creates a high demand for robust and sophisticated production solutions.

The demand for digital solutions and networking concepts is growing, as they hold enormous potential for production. The availability of data independent of time and location enables both seamless process monitoring and the optimization of throughput and reject rates in production.

Since optical technologies guarantee extraordinary innovation advances like hardly any other sector, these digital concepts must find their way into optics production. Especially for products with narrow tolerances, the implementation in complete production process chains is often still based on the trial and error principle until a solution is found iteratively.

In this context, the state of North Rhine-Westphalia is supporting the infrastructure program „EverPro" at the Aachen location, which serves as a basis for the establishment of the Aachen Center for Optics Production (ACOP). This project addresses the networked production of optical systems and thus also the economic success and the development of novel products and product generations.

With this publication we would like to present the research approaches and results of the EverPro project in the context of precision assembly of optical systems. The digitalization concept for optics assembly should enable researchers at the Fraunhofer IPT and partners of ACOP to implement and integrate new assembly processes as well as prototype tools into a flexible machine platform faster in the future, and to capture all relevant data from pre-processes.

Value chain for complex optical systems

Complex optical systems such as curved displays or holistic lighting concepts for ambient lighting in vehicles and buildings, but also high-resolution devices in diagnostics and medical technology consist of a multitude of optical components. All these components pass through a value chain during their production as shown in Figure 1. Along the value chain, a variety of different machines and processes act on the components and generates different types of data using specific measurement systems.

During the design process data can be collected that describe the geometry and the optical function of the components. The simulation provides initial process data, which can be used for analysis of the product and components. During the simulation of the glass forming process, for example, first parameters can be generated which can be used to run the real process. Also, optical tolerance analysis via ray tracing generates image data can be used for the development of active alignment strategies for optics assembly.

Challenges in precision optics assembly

As the final step in the value chain of optical systems design, the assembly process is highly dependent on all previous steps. It is here, at the very latest, that any errors in the product design and tolerances of previous production steps become visible and the overall performance of the system is finally determined. Therefore, the data collected in the respective process steps are very important for assembly. In many cases, unavailable previous knowledge is compensated by closed loop assembly processes. These closed loop process are passive alignment, where the relative position and orientation between two components is evaluated and active alignment, where the function of the overall system is continuously captured and used as feedback for closed-loop positioning. Especially active alignment processes are used to compensate for tolerances of individual components. For all this closed loop assembly strategies, new measurements are made within the assembly systems and processes with separate measuring systems instead of using data from previous processes such as manufacturing or simulation.

In addition to the previous processes, the design of an optical system or components in particular plays a major role in the assembly process and costs. The design and the necessary equipment can change enormously with even the smallest changes in product design. If, for example, a component is no longer accessible due to a change in the housing, the sequence in which the components are assembled must be completely changed. From an economic point of view, the acquisition of assembly equipment, which will also be compatible with sca-ling production, is accompanied by high investments, is risky, and can be a barrier to the development of innovative products or the automation of the existing production.

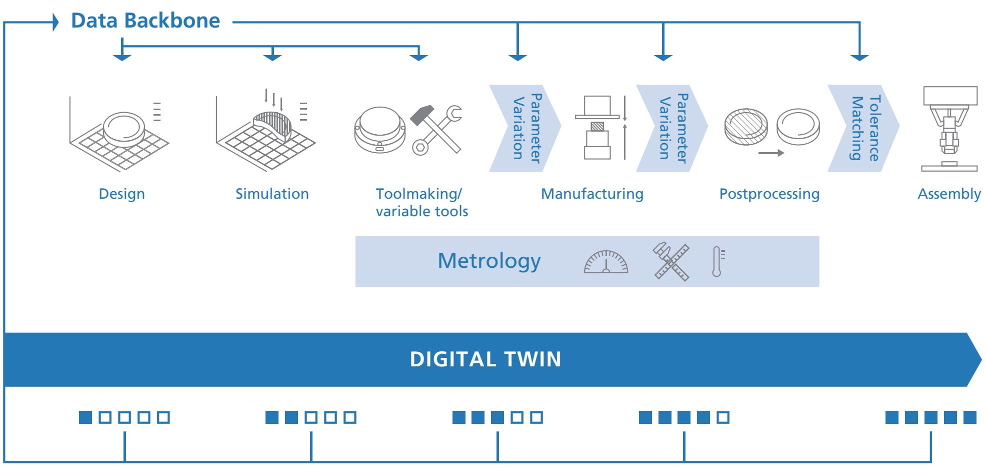

Figure 1: Overview of a value chain for complex optical systems.

TWO NEW APPROACHES PROVIDE SUSTAINABILITY AND EFFICIENCY

To meet the challenges outlined above, EverPro focuses on two approaches:

The first considers an interdisciplinary networking and digitization of the various process steps and systems within the process chain. Through adequate storage, handling and evaluation of process data, these can be used within the assembly to achieve a higher accuracy. In this context, a physical interface is being developed that analyses the component condition and ensures damage-free transport.

The second approach is based on a modular machine platform and extends it by the design of a tool architecture, which allows a fast and easy development and integration of additional tools. This allows the flexibility of the digital infrastructure to be transferred to a physical infrastructure and changes in upstream processes within the assembly to be implemented in a short time.

The goal of both approaches is a sustainable optimization and an efficient process development.

Physical and digital infrastructure

In order to achieve a physical interconnection between optics assembly and the other processes, a transport system must be available that connects the individual process steps with each other and transports the optics on a tray from station to station (Figure 2).

This means that the pieces have to cover longer transport distances without supervision until they arrive at the assembly. Magazine and referencing concepts currently exist only for the design and additive production of the magazines, but do not take into account their continuous monitoring during transportation and use. However, to ensure damage-free transport, the condition of the magazine must be known at all times along the transport chain. For this reason, a "Smart Tray" must be developed on which work pieces can be monitored along their entire transport route with the aid of appropriate sensor technology. These sensors can monitor acceleration, pressure, temperature and acoustic emissions. The evaluation of the sensor data can lead to a considerable increase in accuracy in the assembly process, since the errors occurring during transport can be compensated for in the pre-assembly by tolerance-matching or by construction of individualized sub-assemblies. Also, this information can be used to perform a general evaluation of these optics in advance. This information can in turn be incorporated into quality control.

For example, acceleration or acoustic emission sensors can be used to check whether the work piece together and thus the optics were affected by strong vibration during transport. This could lead to the conclusion that the optics are no longer at their defined position in the tray, which could influence the gripping process of the respective optics within the assembly. Corresponding pressure sensors on the tray can also provide information whether the optics are at the defined positions on the tray. A temperature sensor can provide information about general ambient conditions. These in turn can also have an impact on the optics, which can lead to further tolerance violations within the system An example of such a tray is shown in Figure 2.

To make the sensor data available to the assembly process, these are sent via a defined interface to an edge device, which loads the data into a database. This interface is implemented according to the REST specifications, which results in good scalability, reliability and easy integration of other systems.

Since the sensor system on the tray is battery powered, the design must take into account energy-saving of all components. This battery is monitored independently by the tray, recharging automatically during idle periods at stations that can easily be integrated.

System architecture for rapid tool development and integration

Modular platforms for automated precision assembly are already state of the art and available from a variety of manufacturers. In most cases, only tools from the respective manufacturer can be integrated into these platforms, which makes it difficult to integrate newly developed tools, especially in research and prototyping environments. This also restricts the adaptation of tools or the entire assembly platform due to product changes. Thus the approach in the EverPro research project does not aim at creating a modular machine platform, but rather at developing a tool architecture that allows a cost-efficient and quick development and integration of new tools (Figure 3).

From a mechanical point of view, this architecture defines an interface for the integration. Since most machines can perform a calibration procedure and components are aligned relatively in assembly sequences, absolute positioning accuracy of the tools after integration within the assembly platform is not a priority. A prerequisite is that the tools maintain their position and must not move during operation of the machine. Suitable examples of this can be found in simple, robust and inexpensive interfaces that are already used in optical laboratory equipment, such as optical rails or magnetic holders for kinematic coupling. A portfolio of standard housings and base plates in various sizes can be used as templates for the geometrical dimensions and enables a cost-efficient industrial use of new tools.

With regard to the control system certain considerations must be made: the goal of prototype applications is to develop and test new tools and processes. Many prototype tools such as (vacuum) grippers or camera systems do not perform safety-critical actions. Thus industrial standards do not have the highest priority during prototyping. Open source control systems like microcontroller-based development boards are ideal controls for the tool development in this environment. For programming, lots of open source information is available and the interfaces of state-of-the-art boards like Arduino or Raspberry Pi for Wi-fi, Bluetooth or 5G enable a fast and easy integration into the assembly platform. Furthermore the Internet of Things (IoT) characteristics of these controllers qualify them for a modular machine concept and extensions for the peripherals are widely available for these systems.

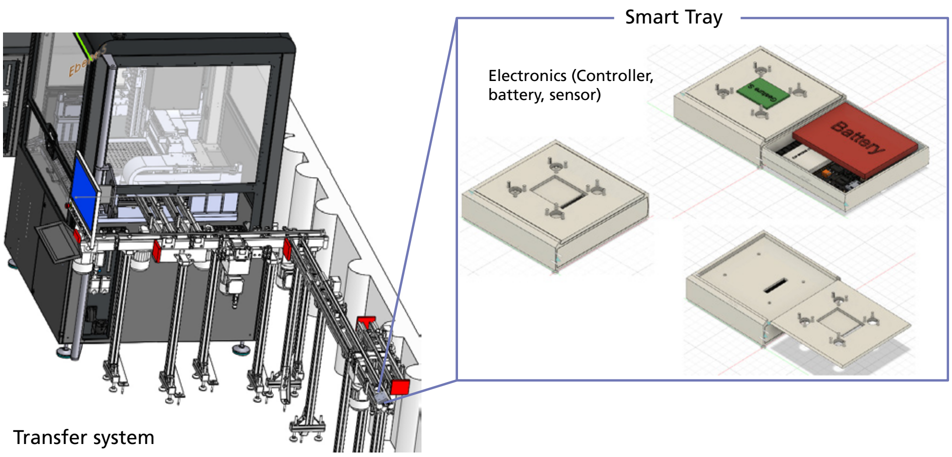

Figure 2: Transport system that carries the components into the automatic assembly machine.

Industrial standards have a high priority in the production environment. Here, robust controllers such as PLC's (programmable logic controllers) are used, which implement the safety standards. The available information for programming these systems is not as widespread as it is in the open source community and in many cases experts and costly licenses for programming are required.

The challenge is to derive a tool architecture which meets the requirements of both environments and allows an easy transfer of a newly developed tool from prototype to production (Figure 3).

So, let's start digitizing the optics industry!

In order to further optimize the assembly process in the future, the upcoming digitization and networking of production processes holds great potential. The aim of the research project EverPro is therefore to develop a cross-technological and transferable infrastructure concept with different process chains for complex products using optics manufacturing as an example. This offers the opportunity to identify errors occurring at an early stage of the process chain with the help of additional sensors and to use these data as additional information in the assembly process. This facilitates the precision assembly and increases the quality of the final product. The development of a Smart Tray, which provides information about the condition of the components during the transport route as well as enabling clear referencing, will support this.

Newly defined interfaces also allow the machine to be designed in a more modular and flexible way, which brings many advantages. These include not only shorter development times and more freedom for the customer, but also a better and easier integration into a digital production environment.

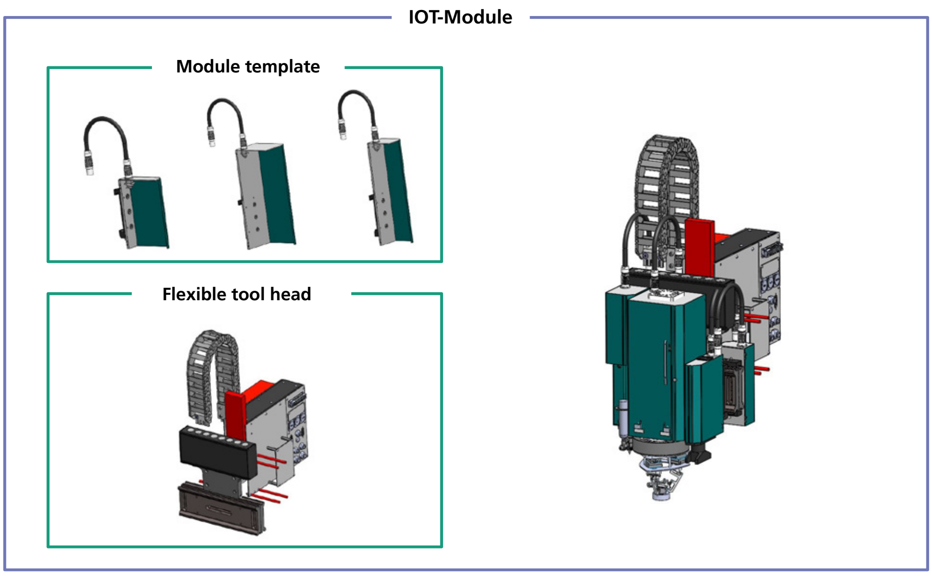

Figure 3: Flexible IOT module

ABOUT THE RESEARCH PROJECT “EVERPRO”

Networking production machines digitally and physically can bring about considerable increases in production output in many areas of industry including the optical sector: once machine data have been logged and evaluated, each individual step in the production process can be mapped in a way that is transparent and thereby paves the way for optimization. The aim of the Fraunhofer IPT within the EverPro project – Efficient Networking of Optical Production Systems – is to create a digitalized production infrastructure encompassing each step in the production of optics and ensuring a holistic, digital production scenario for optics.

Concepts and strategies for digitalization are already under development in many companies both in the optics sector itself and among its customers. However, when it comes to implementing these within entire production process chains, particularly in those involving products with tight tolerances, the guiding principle is frequently one of trial-and-error until a solution is found in an iterative process. In the majority of such cases it is not possible to connect each step involved in the production process fully across multiple process chains.

Networked process chains for optics production

Wherever fault-free production of high-precision components is required, it is particularly important to ensure that individual processes interact smoothly with one another throughout the entire process chain: Efficiency is achieved when not only individual processes but also up and downstream interactions and mechanisms happening across a range of processes are fine-tuned to one another. There exists an enormous potential, especially within the optics industry, for the digitalization of processes and process chains.

Digitalization and data consistency for all steps in the production process

The Fraunhofer IPT, a pioneer in the field of optical manufacturing technologies, is committed to developing a means of ensuring that all individual steps and entire processes are networked efficiently within the framework of the EverPro research project, ready for the next step in the evolution of optics production.

Starting from optics design, continuing through tool and mold making and replication to metrological qualification and final assembly, the Fraunhofer IPT draws on a wealth of background expertise and knowledge of the individual processes within the project.

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Whitepaper Fraunhofer IPT

Authors
Armin Tavakolian M.Sc.
Research Assistant in Precision Assembly and Automation
Maximilian Hoeren M.Sc.
Research Assistant in Precision Assembly and Automation
Cornelia Rojacher M.Sc.
Manager Business Unit Optics

Fraunhofer Institute for
Production Technology IPT
Steinbachstrasse 17
52074 Aachen
Germany
Phone +49 241 8904-0
optics@ipt.fraunhofer.de
www.ipt.fraunhofer.de

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