S. C. N. TÖPFER[1], G. LINSS[1], M. ROSENBERGER[1], U. NEHSE[2], K. WEISSENSEE[1]

[1]Technische Universität Ilmenau
Department of Quality Assurance
Germany, e-mail, susanne.toepfer@tu-ilmenau.de
[2]Mahr OKM GmbH Jena, Germany

AUTOMATIC EXECUTION OF INSPECTION PLANS WITH THE I++ DME INTERFACE FOR INDUSTRIAL COORDINATE MEASUREMENTS

Due to the fast advancement of manufacturing technologies for micro- and nanostructured components and the increasing need for sophisticated inspection methods the paper discusses the prerequisites for automatic execution of inspection plans [1]. Based on the latest state-of-the-art, the setup and operating principle of a closed quality loop for dimensional inspections is described. The ongoing development of manufacturing technologies and the increasing complexity of specimen to be inspected require more than one sensor to perform dimensional measurements efficiently. The I++ DME (Dimensional Measurement Equipment) interface standard enables the interoperability of different measurement software with different coordinate measuring machines (CMM). A novel concept to integrate multiple sensors at one CMM via I++ DME rather than via proprietary interfaces is presented. The outlined novel concept is based on an I++ DME node.

Keywords: inspection planning, micro- and nanometrology, multisensor measurements, I++ DME node

1. INTRODUCTION

Recently a study on the international state-of-the-art in the field of micro-production technologies has been carried out [2]. It emphasises explicitly the importance of quality assurance and measurement technology. Thereby the need to lead back the results of inspection processes for future quality assurance actions or manufacturing process improvements is highlighted. There is a large lack of appropriate inspection technology in industrial production of micro- and nanostructured components [3, 4]. Functional tests, which are usually executed after the assembly of the whole micromechanical product, are state-of-the-art [5, 6]. Approximately 80 percent of the value creation occurs after the wafer level [7]. Thus, significant cost can be saved if the microstructured components can be inspected on wafer level after the structuring processes e.g. etching. Considering wafer bonded components for example, the yield after the decollating of bonded wafers amounts currently to 60 - 80 percent [5].

Considering dimensional inspections of micro- and nanostructured components the huge number of inspection features drives the need for fully automated inspections from the stage of inspection planning to the performance of measurements. Typically very small features for example 100 nm wide structures are distributed over a large area of several square millimetres or even several square centimetres. Due to the nature of the inspection features such inspection tasks cannot be fulfilled by one sensor rather than by a multisensor system. Consequently, the term automated dimensional inspections of micro- and nanostructured components is linked to the deployment of multisensor systems. The I++ DME interface is suitable for controlling automated dimensional inspections.

The development of the I++ DME interface has been initiated by the automotive industry. Lack of interoperability between coordinate measuring machines (CMMs) [8, 9] and related software packages for dimensional inspections was the motivation. Typically one software package is used to operate a specific type of CMM. Thus, one inspection plan, created with a specific software package, could not be utilised for another type of CMM, which was operated with another software package. Therefore one inspection plan had to be rewritten in order to be deployed at another type of CMM. In industrial coordinate metrology the increasing complexity of parts and components to be inspected drives the need for dimensional inspections with multisensor systems. Additionally, the fierce international competition coerces companies into performing all steps of production with the highest possible efficiency, including inspections of product quality. Consequently, each inspection feature has to be inspected with the fastest suitable inspection method. Thereby often a combination of a very fast non-contact optical sensor and a touch probe is utilised.

This paper proposes a novel concept to integrate multiple sensors via the I++ DME interface at one CMM. Thus, the automatic execution of inspection plans for several sensors via the I++ DME interface is enabled. Subsequently the term inspection planning is explained. Afterwards section 3 focuses on dimensional inspections of micro- and nanoscale features and describes the challenges that have to be met. The next section considers the state-of-the-art regarding the information flow. Thereby requirements which are vital for automated dimensional inspections are explained. Section 5 introduces a novel concept for communication, meeting the previously described requirements. Afterwards section 6 explains some specific issues for the utilisation of the novel concept. After the outline of the attained experimental results the paper closes with a brief summary.

2. INSPECTION PLANNING

The term inspection planning is defined in the VDI/VDE/DGQ guideline 2619 [10]. Regarding the overall system described in this paper two aspects of inspection planning should be distinguished. The design-based inspection planning applies the knowledge attained during the design stage. The knowledge-based inspection planning comprises the following three items:

- derivation of dimensional inspection features from the function of the micro- or nanostructured component [6],
- automatic adjustment of the parameters of the probing sensors according to the existing measuring conditions and
- determination of an optimal inspection strategy whereby the knowledge about the characteristics of the available sensors is taken into account.

Thereby the term optimal inspection strategy refers to minimal traverse path, minimal measuring time and a minimal degree of wear (for example AFM tip (atomic force microscope) in contact mode). This is enabled through the precise knowledge of the position and size of the area of the measuring object, where the feature to be inspected is located.

3. CHALLENGES FOR DIMENSIONAL MICRO- AND NANOMETROLOGY

This paper focuses on dimensional inspection of micro- and nanostructured components. This is very important for inspections on wafer level. Thereby, predominantly micro-mechanical products and all other products are inspected, for which geometry and size of structures are suitable for the evaluation of their functionality.

In general, inspections of such components have to cope with a huge number of inspection features, which can be up to 100,000 at one part only. Typically very small features for example 100 nm wide structures are distributed over a large area of several square millimetres or even several square centimetres. Any inspection technology has to span more than one scale of dimension [11, 12]. This is a challenging task.

Moreover the critical dimension is constantly decreasing. Exemplary, the International Technology Roadmap for Semiconductor (ITRS) [13] specifies 21 nm as current maximum value for placement errors of microstructures on photomasks. As Figure 1 illustrates, there is a huge variety of different sensing principles for measuring micro- and nanoscale dimensional features.

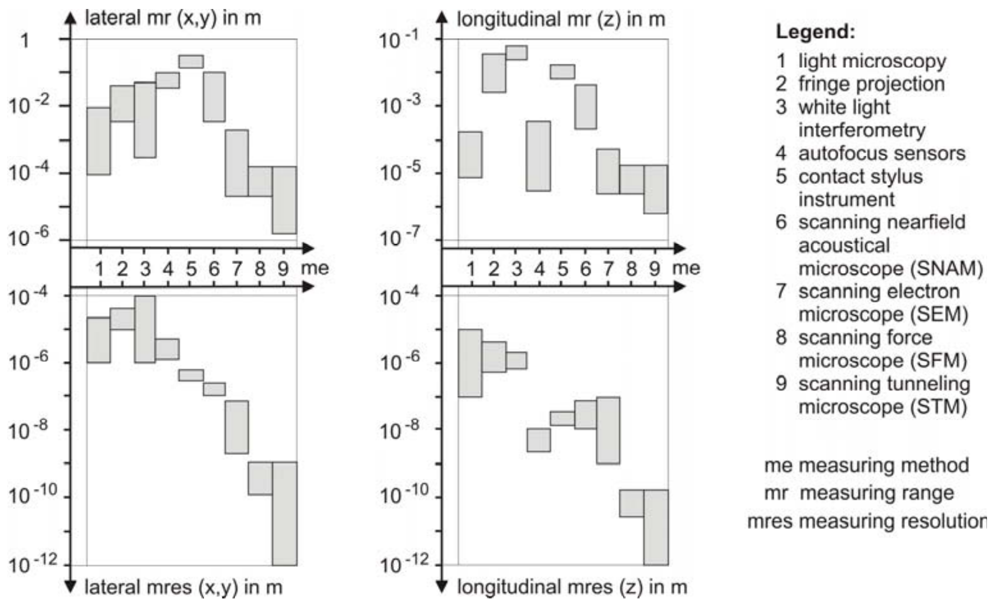

Fig. 1. Resolution and measuring range of typical measuring methods for micro- and nanoscale components [14].

Each method has its own individual advantages and limitations. In order to perform 3D coordinate measurements within the micro- and nanometre range, a combination of different sensors must be utilised. When inspecting nanometric features, surface metrology and dimensional metrology melt together. This can be illustrated by considering the proportion of volume to surface of geometrical primitives, for example sphere, cube and plane. For shrinking dimensions of micro- and nanostructured components the surface decreases only quadratically whereas the volume decreases cubically [14].

Besides this issue, the interaction between the sensor for measuring the component and the measuring object itself becomes crucial with shrinking dimensions. Exemplary - at AFM measurements the recorded raw measuring data have to be interpreted according to the existing physical as well as geometrical interactions between tip and sample [15, 16]. Otherwise wrong measuring results will be attained.

A further issue are suitable tolerances for micro- and nanostructured components. The simple down-scaling of the existing general tolerances for macroscopic features cannot be the sole solution. The so called “Goldene Regel der Messtechnik” (“Golden Rule of Measurement Science”) states that the measuring uncertainty should be ten times smaller than the tolerance of the feature to be inspected. This means that the maximum allowable measuring uncertainty for a structure with a lateral tolerance of 2 nm amounts to 0.2 nm. Current values for measuring uncertainty for measuring the width of structures for example at photomask width standards amounts to 15 nm (k = 2) for SEM measurements and to 24 nm (k = 2) for optical measurements with an UV transmission microscope [17]. During the last ten years tolerance systems, measuring strategies and parameters for describing the properties of micro systems did not change essentially [13]. However, there has been constant improvement of measuring machines and sensors as well as of manufacturing processes. The well known methods and procedures for inspecting macroscopic features respectively the working principles they stand for, should be investigated regarding their applicability in inspecting purposefully features of micro- and nanostructured components. Many of the known inspection strategies in dimensional metrology are not likely to be of use under these conditions, but some may prove to be very useful.

Finally, there are three further criteria for dimensional measurements of microscale components, which have been described by Storz [11]. They apply to nanoscale components as well. They comprise:

- automatic execution of the measuring process,
- short measuring time as a critical factor for the utilisation in industry and
- no change and destruction of the inspected structures.

Moreover, the fixing of the measuring object without introducing stress is also an important criterion. Bader [18] indicates freeze clamping, theological fluidic fixing, needle fixing cushion and electrostatics as possible methods.

4. INFORMATION FLOW FOR AUTOMATED INSPECTIONS

The large number of inspection features of dimensional measurements in the micro and nano range entails a need for a lossless information flow along the process chain [19]. Thereby the process chain comprises computer-aided design (CAD) and computer-aided quality assurance (CAQ) and is characterised by neutral interfaces. From the viewpoint of quality assurance the process chain corresponds to a small closed quality loop (Fig. 2). Its principle applies not only to measurements on the macroscopic scale but also for measurements on the micro- and nanoscale. In [20] a detailed description of the application of this principle for inspecting micro- and nanoscale features is given.

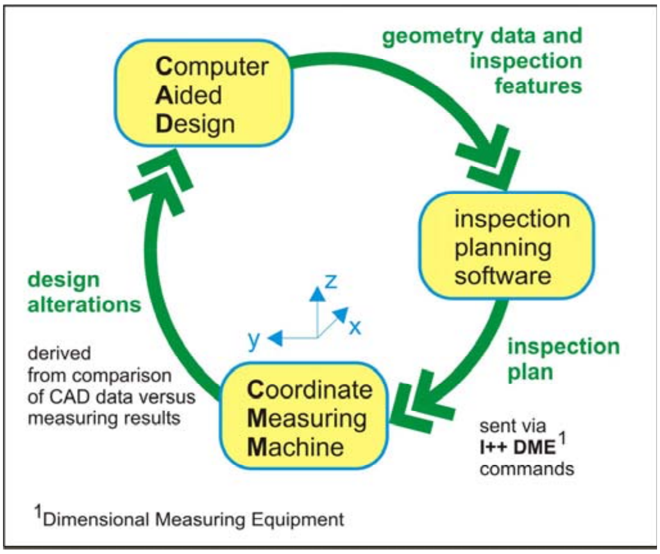

Fig. 2. General set-up of a closed quality loop for dimensional measurements with coordinate measuring machines (CMM).

The state-of-the-art is represented by the recently accomplished adaptation of the closed process chain to the nano-positioning and nano-measuring machine (NMM) [21] (Fig. 3). Thereby, novel principles of knowledge distribution and novel inspection strategies have been outlined. As Figure 3 shows, the closed process chain starts with the design of micro- or nanostructured parts or components with the CAD system *ProEngineer*. The geometry data are saved as STEP-file. The module *PE-Inspect* is used to export the list of inspection features as QDAS-file. Both files are imported in the offline programming system (OPS) which is also referred to as inspection planning system. The OPS, namely *Calypso*, is used to perform the inspection planning, which can be done offline. Typically the OPS supports the neutral I++ DME (Dimensional Measuring Equipment) interface [22]. Consequently, it allows initiating the automatic execution of an inspection plan. Thereby the OPS and the measuring software are communicating bidirectionally via the TCP/IP protocol.

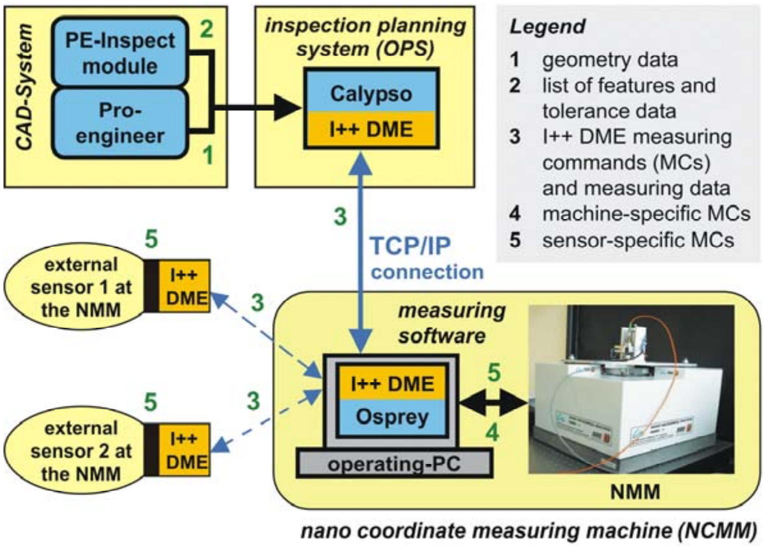

Fig. 3. Closed process chain for dimensional measurements of micro- and nanostructured components utilising the NMM

The measuring software, namely *Osprey,* incorporates the server side of the I++ DME interface. The OPS transmits the previously created measuring sequence via the I++ DME interface to the measuring software. The I++ DME server of the measuring software interprets the received I++ DME commands as machine-specific commands for the NMM. These commands are directly executed by the NMM. The recorded measuring raw data are corrected e.g. sensor specific corrections, machine specific corrections. The correct measuring data are sent back to the OPS, where the comparison between CAD data and actual measuring data is performed. Due to the observed deviations, design alterations or adaptations of manufacturing processes are initiated. Many of the I++ DME commands involve the utilisation of the probing sensors of the measuring machine. If touch probes are to be used, the communication between measuring software and sensor (illustrated in Fig. 3, comprising any connection of type 5) utilises the known standard interfaces for touch probes e.g. the *Renishaw* interface. If optical sensors are deployed, the measuring software (e.g. *Osprey*) or the directly connected I++ DME interface communicates via the Optical Sensor Interface Standard (OSIS) with these sensors.

Currently over 200 types of optical sensors are on the market. Many sensor principles are available whereby each of them has advantages for specific measuring tasks. Thus, besides some widely spread sensor types, there are many niche sensors. The motivation for the initiation of OSIS lies with the complex integration of optical sensors in coordinate measuring machines (CMM) and with the related high economical and technical risks for CMM manufacturers and sensor manufacturers [23]. After three years of intensive collaboration of about 25 companies from Asia, America and Europe the first version of the documentation of OSIS has been published in 2004 [24].

The closed process chain for dimensional inspection of micro- and nanoscale components incorporates the I++ DME interface instead of the Dimensional Measuring Interface Standard (DMIS) [25] for different reasons. Firstly, the interoperability of different measuring machines with measuring sequences written in DMIS is not generally given. Secondly, DMIS has only very limited capabilities for deploying optical sensors. Thirdly, DMIS allows no online communication between the measuring machine and the OPS. However, the utilisation of DMIS for offline inspection planning and archiving inspection plans will continue. Based on the international state-of-the-art, the standard interface I++ DME has been chosen. This interface emerged in 2000. It allows not only dimensional inspections with touch probes but also with optical sensors. Thereby the I++ DME standard integrates the novel OSIS interface. The I++ DME interface [8] is an open neutral interface which encapsulates the expertise of the manufacturer of the measuring machine. At the same time due to the international standardisation efforts [26], it enables the maximum interoperability between different dimensional measuring equipment (DME), for example CMMs, and different inspection planning and programming software.

The progress and fast increasing establishment of the I++ DME interface can be judged from interoperability tests (Fig. 4), which have been demonstrated in April 2005 at the Fair „Control" in Sinsheim, Germany. The tests were performed by the international association of CMM manufacturers (*inter alia*, cmm, Europe) with support from the National Institute of Standards and Technology (NIST, USA) and from the Automotive Industry Action Group (AIAG, USA). Thereby each of the five different CMMs has been operated via the I++ DME interface with six different software packages (Fig. 4) for offline programming (OPS). The CMMs were from Hexagon Metrology SpA (Italy), Renishaw plc (UK), Trimek Metrologica Engineering (Spain), Wenzel Präzision GmbH (Germany) and from Carl Zeiss Industrielle Messtechnik GmbH (Germany).

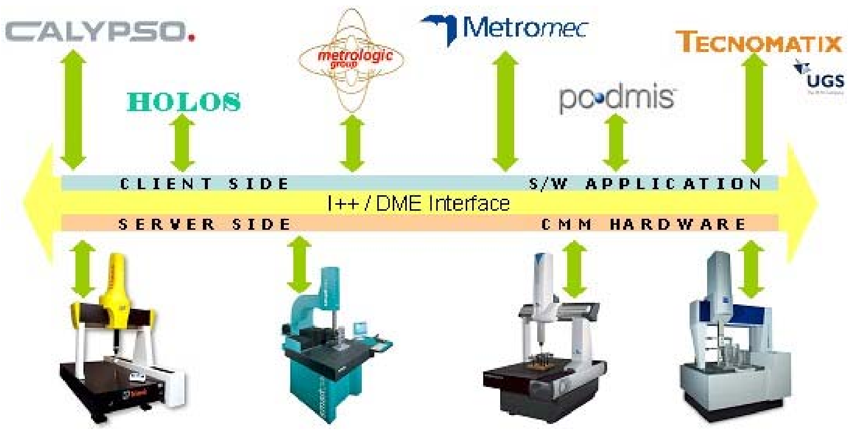

Fig. 4. Novel level of interoperability between CMMs and inspection planning software [27].

The next section explains in detail the setup of a communication structure based on the I++ DME interface. This setup shall enable automated dimensional inspections with distributed multisensor systems. The core of the communication structure is the so-called I++ DME node.

5. WORKING PRINCIPLE OF THE I++ DME NODE

5.1. Setup of the I++ DME Node

The following part of the paper describes the schematic assembly of the I++ DME node. From a technical point of view the I++ DME node equals a proxy. A proxy is an agent placed between client and server. It traps messages and supports special services [28]. Internal systems and external systems respond to the proxy server. Thereby the internal systems are connected to the outside world through the proxy server. In contrast to the utilization of routers, including routers with network address translation, the proxy hides the network of internal systems from the external systems [29]. The external systems know only the interface of the proxy server. The I++ DME interface standard uses a TCP/IP connection. It enables the communication between inspection planning software (OPS) and measuring hardware. In our application the components inspection planning system and CMM are network devices. The basic case for network communication is a peer to peer connection between the devices. In our specific case the CMM acts as a server and the inspection planning software as a client.

The I++ DME standard provides special commands which allow the communication about the measurement task between the inspection planning system and the CMM. Thereby the inspection planning system (I++ DME client) sends a message to the I++ DME server, for example the request of a positioning action. The I++ DME server converts the command into a machine-specific format. After that, the coordinate measuring machine drives to the desired position. As feedback, the server generates and sends a message to the client about the completion of the action. The content of the message is the actual position of the CMM. In cases of failure an error message will be sent by the server.

If additional sensors without a TCP/IP interface option are to be deployed at the CMM, a problem of system compatibility occurs. It comprises mainly the integration of the electrical, mechanical and software interface of the additional sensor. The function scope of the I++ DME node offers a new approach for avoiding the compatibility problem. This novel approach enables new possibilities for the fast integration of sensors.

The I++ DME node consists of logical units as a shared system on one hardware platform or as a shared system on several hardware platforms. Additional sensor techniques are now capable of communicating with a CMM over a TCP/IP connection. Thus, it is no longer necessary to implement proprietary interfaces in order to utilise additional sensors, provided that these sensors have an I++ DME interface. The data exchange between several sensors, mounted on one CMM, and the inspection planning system is now supported by the novel system.

5.2. Connections of the I++ DME Node

According to the I++ DME standard the connection is established between an I++ DME client and an I++ DME server (Fig. 5). This connection is a bidirectional communication via a TCP/IP socket. A socket is a link between two applications. Usually the link is established within a computer network. However, it is also possible to realize it on the same machine. The term bidirectional means that the application can receive and send data at the same time. When establishing the connection, the I++ DME server starts to bind a port on the local machine to the application. When the I++ DME client connects to this port on the server machine, the socket is open and is able to receive or send data.

In an I++ DME communication the I++ DME client is the socket client and the I++ DME server is the socket server. The client application is the application which manages the measurement task. The I++ DME server implements all functions required to drive the measuring machine e.g. CMM and control of all sensors. The I++ DME client sends commands to the I++ DME server in order to execute elementary measurement tasks, e.g. measurement of points, scanning. The server listens and responds to the commands of the I++ DME client.

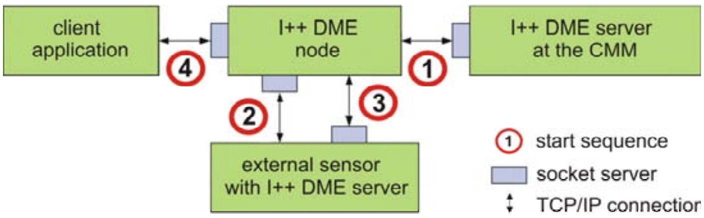

Fig. 5. I++ DME structure containing an application, an I++ DME node, a CMM and an external sensor.

The I++ DME node has a socket connection to all other components. It acts as a socket server for the connection to all I++ DME clients. For the connection to the two I++ DME servers it works as the socket client. The second connection between the I++ DME node (server side) and the external sensor (client side) enables the control of the CMM through the external sensor (Fig. 5). In summary, the I++ DME node incorporates two I++ DME servers and two I++ DME clients. In order to start all four components with the right reference to each other, it is necessary to consider the start sequence.

5.3. Start Sequence and Command Flow for a Distributed I++ DME Multisensor System

The first step is to start the I++ DME server at the CMM. Afterwards the I++ DME node is started and connects itself to the previously started I++ DME server at the CMM (no. 1 in Fig. 5). Thereafter the I++ DME client of the external sensor connects to the I++ DME node (no. 2 in Fig. 5). Through this connection the external sensor has the capability to retrieve the actual position and the machine parameters of the CMM via the I++ DME node. It is also able to send movement commands to the CMM. The second connection enables the I++ DME node to send measuring commands to the external sensor. This connection is established after the initialisation of the I++ DME server of the external sensor has been completed. Thereby the I++ DME node connects to the I++ DME server of the external sensor (no. 3 in Fig. 5). Finally, the application client connects to the I++ DME node (no. 4 in Fig. 5). It is the task of the I++ DME node to send commands from the application client to the appropriate I++ DME server.

The following use cases shall clarify how the I++ DME node alters the command flow (Fig. 6).

1. The first sequence diagram shows a change of the measuring sensor. This example demonstrates a change to the external sensor.
2. The second command moves the CMM.
3. Finally, the measurement of a circle is illustrated. In this example the external sensor will move the CMM in order to perform the measurement.

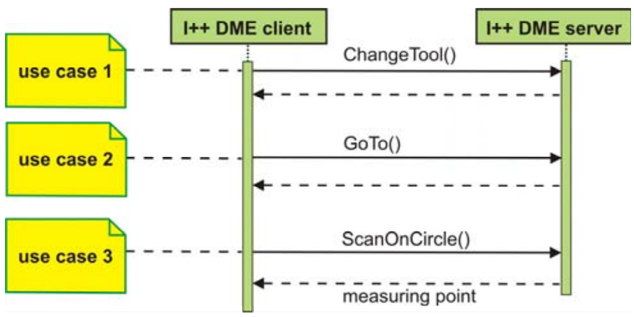

Fig.6. Typical I++ DME command sequences for a client-server-system.

It is necessary to differentiate the commands. Otherwise the properties of the reference sensor will be destroyed through commands intended for the external sensor. The reference sensor is directly integrated at the CMM. It is operated via the I++ DME server of the CMM (CMM server). The movement command shall serve as an example. Considering case one, this command is sent to the reference sensor. Thus, the CMM server moves the measuring machine to the requested position. Considering the second case, the movement command is sent to the external sensor. After converting the movement command into its coordinate system, the external sensor sends the modified command via the I++ DME node to the CMM server. The coordinates of the movement command, received by the CMM server, are valid for the external sensor. The CMM moves and is finally aligned for measurements with the external sensor. This demonstrates the necessity to differentiate the commands.

Consequently, five groups of commands can be derived:

- first group: commands valid for the I++ DME server controlling the active sensor, e.g. *GoTo*, *ScanOnCircle*,
- second group: commands valid for all I++ DME servers, e.g. *StartSession*, *ClearAllErrors*,
- third group: commands valid for the I++ DME server controlling the CMM and the reference sensor, e.g. Home, *GetMachineClass*,
- fourth group: command valid for the I++ DME server controlling the external sensor,
- fifth group: unknown commands.

The I++ DME node always has to be aware which sensor is active. Otherwise errors will occur. Furthermore, the knowledge about all sensors at all servers is important for the I++ DME node in order to send *ChangeTool* commands to the correct server. All movement and measuring commands, sent by the I++ DME client of the inspection software, are forwarded by the I++ DME node to the I++ DME server of the active sensor only.

Only the I++ DME server controlling the CMM will receive machine specific commands like moving to home position and information about the CMM type. All commands, which are related to properties for changing the coordinate system and related to information about sensors, can be sent to any I++ DME server controlling at least one sensor. Some commands need further processing. For example, the command *EnumTool* requires the I++ DME node to merge the responses of the I++ DME servers of the external sensor and of the CMM. The merged answer is sent by the I++ DME node to the client of the inspection planning software.

Currently, specific I++ DME commands for optical imaging sensors are not used. This group will be specified in a future version of the I++ DME standard. One of the next releases will contain some commands for imaging sensors. Our I++ DME server for the optical sensor is able to perform measuring commands which have been intended for touch probes. Thus, the I++ DME node is able to control optical and tactile measurements. The command group of unknown commands shall prevent the occurrence of errors. If the I++ DME node receives an unknown command, it returns the error message “unknown command”.

6. PECULIARITIES OF I++ DME CONTROLLED MULTISENSOR SYSTEMS

This chapter shall outline some of the peculiarities of multisensor systems, which are operated via an I++ DME node. The previously described I++ DME structure does place some inherent difficulties to be handled. There are three main issues which are decisive for the operation of the multisensor system. These are the management of the different sensor coordinate systems, the calibration of the multisensor system and the determination of the traverse path of the individual sensors.

6.1. Management of Sensor Coordinate Systems

Typically each sensor has its own coordinate system. The origin of the sensor coordinate system of a tactile probe is usually situated in the centre of its probing element e.g. probing ball. In contrast, the origin of the sensor coordinate system of an imaging sensor e.g. CCD sensor is usually located laterally in the centre of the field of view and vertically in the sharpness plane. Basically, if sensors are utilised via I++ DME, the software belonging to the sensor must support the handling of its sensor coordinate system.

6.2. Calibration of the Multisensor System

First of all, each individual sensor must be calibrated. As this is state-of-the-art it is not considered further. A very interesting task is the calibration of the individual sensors to each other. Basically the goal of this specific calibration step is to determine precisely the three dimensional distances between the origins of the different sensor coordinate systems. There exist various possibilities to realise this functionality. The simplest method is the establishment of an object coordinate system (OCS) at one measuring object with both sensors. At first the OCS is measured with the sensor of the I++ DME server directly connected to the CMM. Afterwards the same OCS is measured with the external sensor connected to the I++ DME node. Crucial at this step is the request of the current position of the CMM from its I++ DME server. This request is sent by the I++ DME client of the external sensor. The I++ DME node receives this request and forwards it to the I++ DME server of the CMM. Thus, both sensors are calibrated to each other.

6.3. Calculation of the traverse path of the sensors

Because the I++ DME standard is currently predominantly suitable for tactile sensors, the utilization of other types of sensors poses the issue of calculating the traverse path for these sensors. Therefore sensor-specific routines for the execution of I++ DME measuring commands must be integrated into the software of these sensors. These routines ensure the calculation of suitable traverse paths for the non-tactile sensors.

7. EXPERIMENTAL RESULTS

The proposed closed process chain for dimensional measurements of micro- and nanostructured components as shown in Fig. 3 has been set up at the TU Ilmenau. Its operability has been demonstrated several times and is described in detail in [30].

Consequently this section focuses on the utilisation of the I++ DME node as a means for communication in a distributed multisensor system. After the theoretical explanation of the I++ DME node, it is necessary to verify the model through practical experiments. Therefore some tests were performed at the Department of Quality Assurance. First tests were executed with the I++ DME test tool provided by the National Institute for Standardization and Technology (NIST) [12].

The tests are divided into two steps. In the first step the test assembly, two optical sensors with one CMM for each sensor, has been controlled by the I++ DME standard solution. This has been done in order to demonstrate the general function of two CMMs with one optical sensor each controlled by a single I++ DME client. Thereby two parts of nearly identical shape have been measured. *Calypso* was used as the inspection planning system respectively as the I++ DME client. After the successful test the new approach - the function of the I++ DME node - was tested. The test system illustrated in Fig. 7 had two sensors, a *Renishaw* touch probe and an optical zoom sensor *OKM Zoom 10x*. Both sensors have been mounted on a single CMM (Fig. 8).

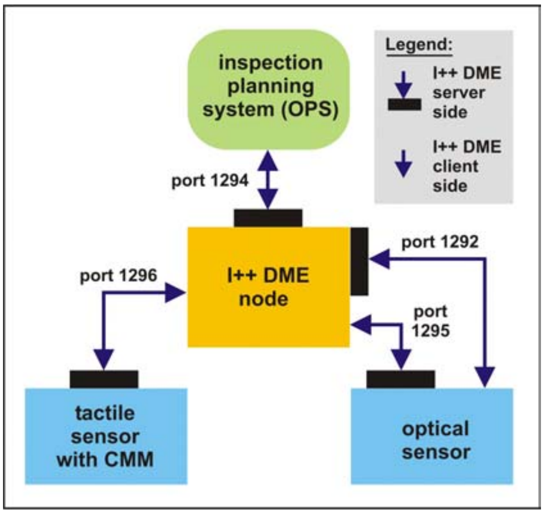

Fig. 7. Schematics of an experimental assembly.

Fig. 8. Deployed multisensor CMM.

Each sensor was configured as an I++ DME standard conform device. In the test system every I++ DME device had its own hardware platform respectively a PC. That means the system was divided into four parts with four hardware platforms, the I++ DME client with the inspection planning system, the new I++ DME node, the I++ DME server for the tactile sensor and the I++ DME server for the optical sensor. All devices were connected via a TCP/IP connection. The measuring task was the measurement of the outer diameter of a flat ring at the measuring object depicted in Fig. 9. The large cylinder in the upper left corner in this figure is part of the zoom system which is connected to the optical sensor. As Table 1 shows, the tests were successfully performed. The measuring results of the tactile and of the optical measurement are identical within the scope of the measuring uncertainty of the deployed sensors. The actual difference between the two diameter measurements is 1.9 µm. Thus, the suitability of the I++ DME node for industrial coordinate measurements has been proven.

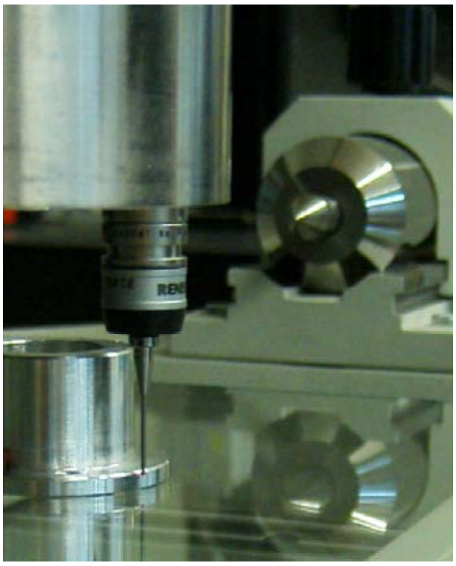

Fig. 9. Measuring object (left part) during the tactile measurement on the CMM.

Table 1. Measuring results of the diameter measurement with different sensors via the I++ DME node.

index	x [µm]	y [µm]	z [µm]	r [µm]	d [mm]	f [µm]	s [µm]	n
1	39948.0	-37711.2	-32891.4	20030.6	40.0612	5.45	2.45	7

2	39944.8	-37710.8	-32475.2	20029.6	40.0593	0.07	0.02	53
deviation	3.1	-0.4	-416.2	1.0	**0.00192**			

CMM name:	UNIVIS 250
x,y,z:	coordinates of the centre point of the measured circle
r, d:	radius respectively diameter of the measured circle
f:	form deviation of the measured circle
s:	standard deviation of the measured circle
n:	number of measuring points

index	**1**	**2**
sensor type and its parameters	**optical** coaxial transmitted light light intensity = 22.4 % zoom lens magnification: 5x CCD camera (1000 x 1000 pixels) dynamic threshold	**touch probe** probe radius = 500 µm switching probe ph6 with TP20 Renishaw control unit P112
alysis of the measuring points	Gaussian circle using a 0.5 sigma filter	

8. CONCLUSION

After outlining the concept of closed quality loops for automated dimensional inspections of micro- and nanostructured components, the information flow has been discussed. As initially explained, dimensional inspections of micro- and nanostructured components require multisensor systems. In order to perform automated dimensional measurements of micro- and nanostructured components with multisensor systems a sophisticated communication concept is crucial. This paper introduced such a concept namely the I++ DME node. The I++ DME node is a novel structure for controlling a distributed I++ DME multisensor system at one CMM. This concept overcomes the difficulties linked to proprietary interfaces. Any sensor whose software has an I++ DME interface can be easily connected to the I++ DME node. Thus, a multisensor system utilised at a CMM can be easily expanded. The applicability of the novel concept has been proven by experimental results.

Future research will focus on further investigation of the calculation of traverse paths of non-tactile sensors and on the automatic adjustment of the sensor parameters. Additionally multisensor measuring strategies, which may be abstractly described and implemented in the I++ DME node, shall be investigated.

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