Implementation and analysis of an automated multiscale measurement strategy for waver scale inspection of micro electromechanical systems

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In this contribution the complete implementation of an automated multiscale measurement system (AMMS) for the inspection of micro lenses and micro electromechanical systems is presented. The system uses an adaptable active exploration strategy to balance the conflict between lateral resolution, axial accuracy and measurement duration. It is equipped with several sensors with different fields of view, resolutions and accuracies. The sensors are linked flexibly during the measurement process by image processing and data fusion algorithms. The image processing algorithms are used to identify defect indicators which represent possible unresolved defects in the current sensor scale. The information gathered by the indicator algorithms results in new regions of interest and information of the specimen feature which are needed to select and to condition more finely scaled sensors, and to trigger higher resolved measurements in the next scale. For the automated adaptation and parameter optimization of the system to a measurement task, an assistant system for sensor and algorithm selection is used. We present the necessary components for automatic task adaptation and active exploration of micro lenses and micro electromechanical systems (MEMS). Inspection results for MEMS-waver and micro lens arrays and a performance analysis are discussed.

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NOMENCLATURE

AMMS = automated multiscale measurement system

CM = confocal microscopy

CCM = chromatic confocal microscopy

FOV = field of view

MEMS = micro electromechanical system

MOEMS = micro opto-electromechanical system

ROI = region of interest

1. Introduction

The quality inspection of micro electromechanical systems during the production process is an important aspect to keep the product quality high and to reduce the production costs. Especially the production process development would benefit from complete geometrical inspection during different process steps. But such a complete geometrical inspection is a difficult task [1] because MEMS usually consist of several complex subcomponents with micrometer dimensions and required tolerances down to submicron while the overall inspection volume for single MEMS is up to 1cm^3. These requirements lead to a conflict for the inspection systems between resolution, measurement time and field of view (FOV) due to the restricted area-related lateral and axial resolution of state of the art sensors.

Single sensor inspection systems are usually a highly specialized solution to a small set of possible defects and a limited number of specimens. In Osten et al. several systems for the inspection of MEMS have been presented [2]. The disadvantage of these solutions is the lack of flexibility. If the measurement task changes, the system, typically, cannot easily be adapted to the new specifications.

More flexibility is achieved by using multi sensor systems. Multi sensor coordinate measurement systems are commercially available, but a still unsolved problem in such systems is the automated task adaption and sensor cooperation. In [3, 4] an active exploration strategy has been described which uses defect indicators to automatically combine different sensor systems by a feature based sensor communication. This approach provides a higher flexibility in comparison to single sensor concepts. Further more it provides a reduction of inspection time because high resolution is only used where it is needed.

A different multi sensor approach is the parallel combination of sensors [5]. This approach offers a high inspection rate. But the flexibility of the system is reduced and changes of the specimen properties typically lead to a high financial effort.

In this contribution, we refer to the approach presented in [3] and show an implementation of such an active exploration strategy into an automated multiscale measurement system (AMMS) for the inspection of MEMS.

2. Multiscale measurement strategy

The AMMS is based on an active exploration strategy (fig. 1) which starts with a fast, low resolution global measurement of the complete specimen. These measurement results are checked for defects and indications for unresolved disturbances by image processing algorithms. In difference to defect detection, indicators are only hints for a defect. Not enough information is available to classify or even characterize a certain indicated region. Examples for indicators are variations in scattering behavior or changes in the confocal raw signal.

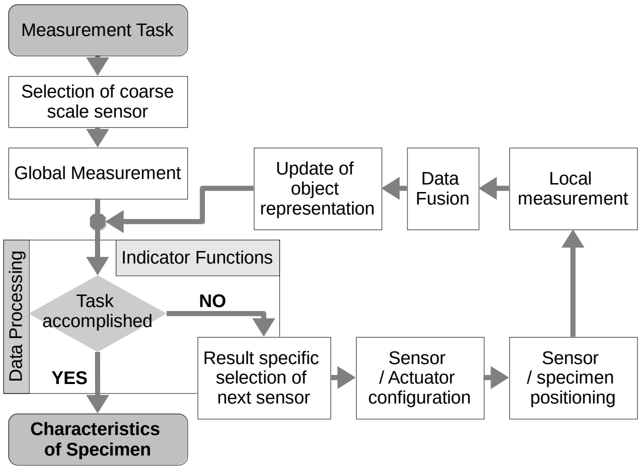


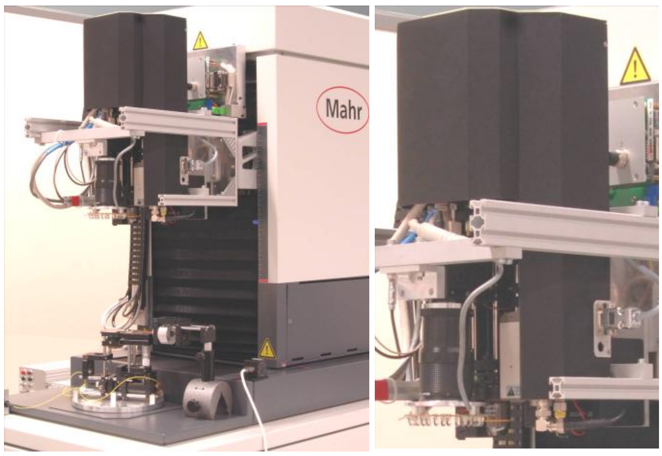
Fig. 1 Differentiation of process monitoring regarding the relation of the measured signal to the monitored parameter

In case of defect indication, a sensor with a higher resolution is selected and its parameters are adapted to measure the region with the suspected defect. With this further measurement a defect characterization is achieved. This procedure is repeated until all defect indications are characterized according to the inspection task.

3. AMMS Sensor hard- and software

To verify the measurement strategy for the inspection of micro optoelectro-mechanical systems, a demonstrator with different sensor systems has been implemented. The system is based on a Mahr MFU-100 coordinate measurement machine with an operating volume of 200 mm x 300 mm x 360° (fig. 2). To fulfill the different requirements of multiple sensor systems and to increase the positioning accuracy, a custom made control system has been developed and implemented [6].

The machine uses a self developed sensor support that offers slots for up to three different sensor systems. In the current configuration the systems uses a video microscope (VM) with a telecentric lens and different measurement modes (dark field, bright field, back plane illumination for spot observation) in the first scale. The microscope employs a color camera with 1.4 million pixels and a field of view (FOV) of 19 mm x 12 mm. In the second scale a confocal microscope (CM) is used for topography measurements. Depending on the mounted front lens, FOVs between 3840 mm and 192 mm and axial resolutions of 0.9 µm down to 0.02µm are available [7]. The last sensor slot is equipped with a chromatic confocal point sensor or a sensor based on the chromatic confocal spectral interferometry (CCSI) principle [8]. For the inspection of MEMS a Mirau CCSI-sensor with a numerical aperture of 0.6, a working distance of 2 mm and an axial resolution around 0.02 µm is used.



a) b)

Fig. 2 (a) AMMS Demonstrator with three sensors; (b) zoom into the sensor head

The measurements with different sensor systems are coordinated by a measurement sequence control program implemented in Matlab. The program registers the measurement data to a common coordinate system related to the MFU axis and creates a complete representation of the specimen. From the registered measurement data of each scale the control program calculates new regions of interest using the indicator evaluation data and specifies the corresponding measurement requests for different sensors. These measurement requests contain information about the measurement position in MFU-axis coordinates, sensor parameters (e.g. measurement range, sample rate, objective lens and evaluation algorithm).

For the automatic sensor selection and configuration with respect to a given task, an assistant system is currently under development [9]. This assistant system uses sensor and actuator models to calculate the most suitable set of parameters to fulfill a given measurement task with a short measurement duration [6, 10].

4. Implementation for MEMS inspection

Due to the high diversity in MEMS layouts depending on the MEMS function and fabrication process we concentrated for the first implementation of the inspection system on a small subset of micro calibration devices. As an example we took the micro calibration devices developed by the IMTEK, Freiburg (fig. 3) [11, 12].

These calibration devices are designed for the calibration of micro displacement and micro force measurement systems. Using a comb drive the device transforms a defined voltage into a defined movement of a mass held by springs and flexures. It can be used vice versa transforming an displacement of the mass into a voltage. The mass of the moving part and the stiffness of the springs are specified so the device can be used for dynamic and static calibration tasks.

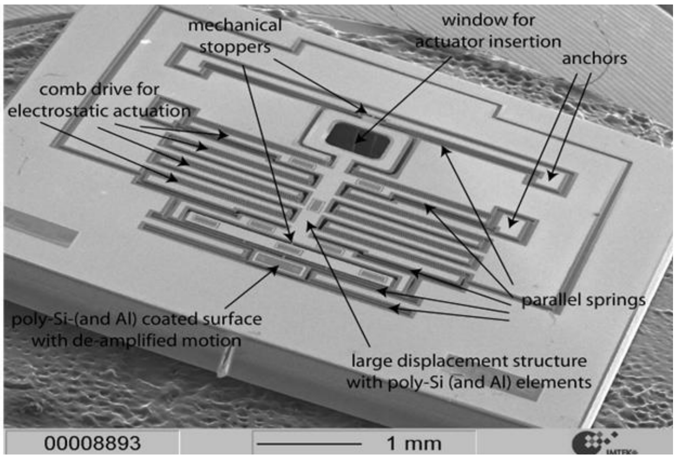


Fig. 3 Picture of in-plane calibration device

The devices consist of the following critical components: optical detection areas, comb drives, springs and flexures, contact areas and contact lines, the moveable mass system and the base structure. The overall size of the micro calibration MEMS that are used is 8 mm x 8 mm. The springs have a length of around 1125 µm and their width is 10 µm. The comb drive consists of up to 500 combs with a width of 10 µm and a gap of 4 µm.

Typical defects of the devices during the fabrication process development are broken or missing combs or springs, cracks and scratches in all regions of critical components. Further more the devices have to be tested for pollution or fabrication errors which can lead to blocked comb drives and springs or create short cuts. The inspection task for the AMMS is to find these defects on a complete waver (fig. 4).

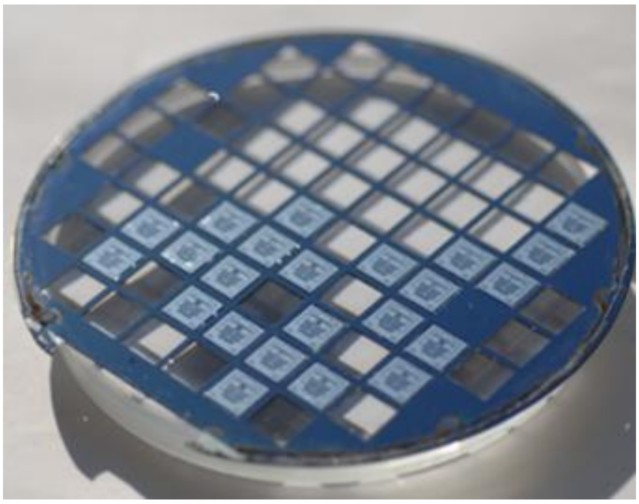


Fig. 4: 3” Waver with micro calibration devices, 72 MEMS before separation.

To find broken springs or missing combs the sensor resolution has to be better than 10 µm. For the characterization of cracks, shortcuts in the comb region and blocked comb drives the sensor resolution has to be even better than the 4 µm gab.

4.1 Measurement procedure

The inspection of a complete waver with the necessary resolution in the finest scale requires three different sensor scales. In the first scale the complete waver is sampled with the video microscope in bright field. The measurements are used to detect the positions of the different MEMS and the critical comb drive regions. In the second scale the confocal microscope with a 10x objective lens is used to measure every comb drive region on the waver. The FOV of the second scale is 1900 µm x 1300 µm with a lateral resolution of approximately 10 µm and a depth resolution of 0.2 µm. In the last scale the confocal sensor and a 50x objective lens with a 0.8 numerical aperture are used to characterize every indicated defect. The FOV of the last scale is 384 µm x 260 µm with a depth resolution of 0.05 µm and a lateral resolution better 2 µm.

4.2 Defect indication and detection algorithms

During the inspection process no additional markers on the waver are used and the alignment of the waver at the beginning of the measurement process is unknown. Hence an algorithm based on Hough-transformation and correlation is applied to identify the different MEMS and the comb drives within the different images of the video microscopic measurements in the first measurement scale. In figure 5 a measurement with the video microscope is shown. The position and the rotational angle of the waver and the calibration devices are unknown.

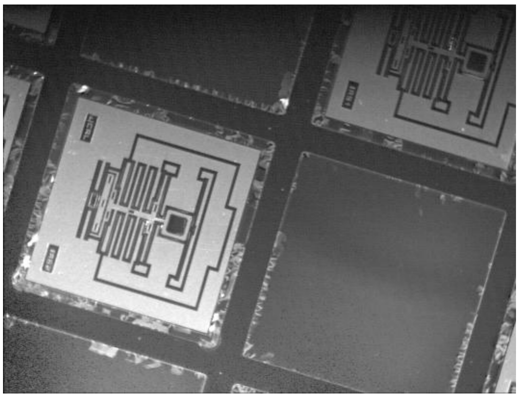


Fig. 5: Image of a waver with calibration devices recorded with the video microscope.

For the preprocessing the local entropy is calculated to enhance differences and to suppress camera noise (fig. 6a). In the next step a Sobel-filter is applied to the entropy image to find edges (fig. 6b).

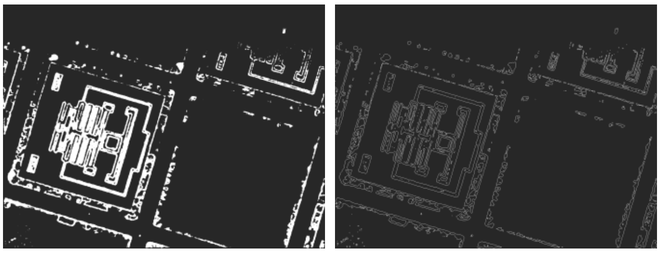


Fig. 6: (a) Entropie filtered and (b) Sobel-filtered picture of fig 4.

The orientation of the MEMS is computed based on the edge orientations from the Sobel-filtered image using the Hough-transform (fig. 7a). Afterwards the original measurement is rotated to achieve the MEMS horizontal alignment of the MEMS structures (fig. 7b).

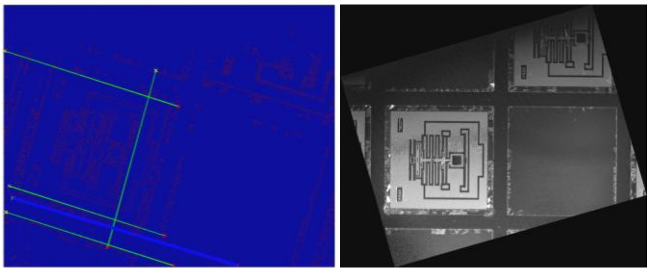


Fig. 7: (a) Hough-transformation and (b) rotated picture of fig 4.

The positions of the MEMS and their critical components are computed by correlating the result shown in figure 6b with a master image of a single MEMS. The positions of the components are marked in a binary defect mask as new regions of interest for the measurement sequence control system (fig. 8).

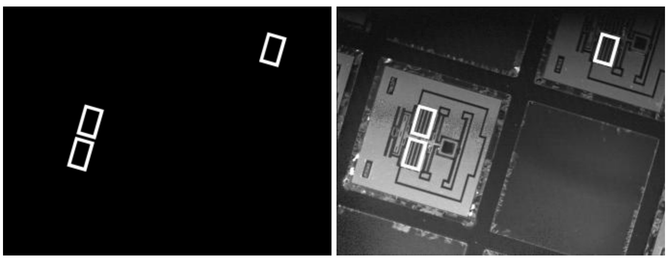


Fig. 8: Marked comb drive regions for fig. 4 after correlation with master image and rotation to the original orientation of the image

In the second and third scale algorithms based on wavelet analysis for the indication and detection of missing combs from 10x and 50x confocal intensity images are used [13].

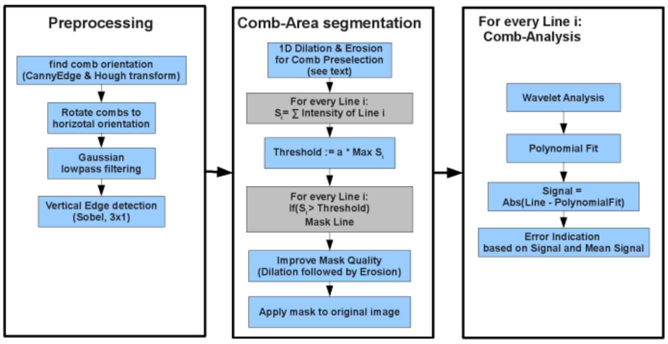
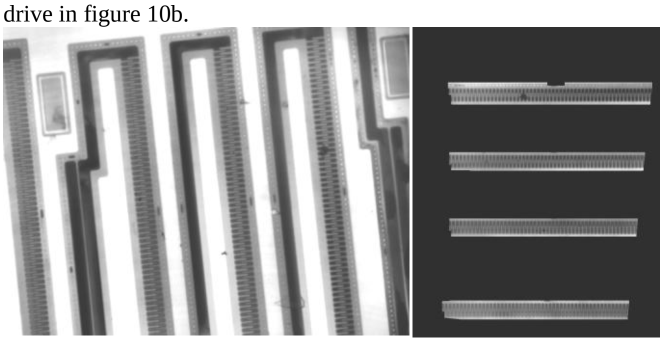


Fig. 9: Algorithms for comb drive defect indication and detection

Figure 10 show the result of the preprocessing from a confocal intensity image (fig. 9a) to the segmented and preprocessed comb drive regions. Figure 11 shows the results of the wavelet analysis from the slice through the middle pixel line of the second comb drive in figure 10b.



a) b)

Fig. 10: (a) Intensity image from a confocal measurement of the a comb drive region with 10x measurement (b) segmented combs for defect detection (contrast enhanced).

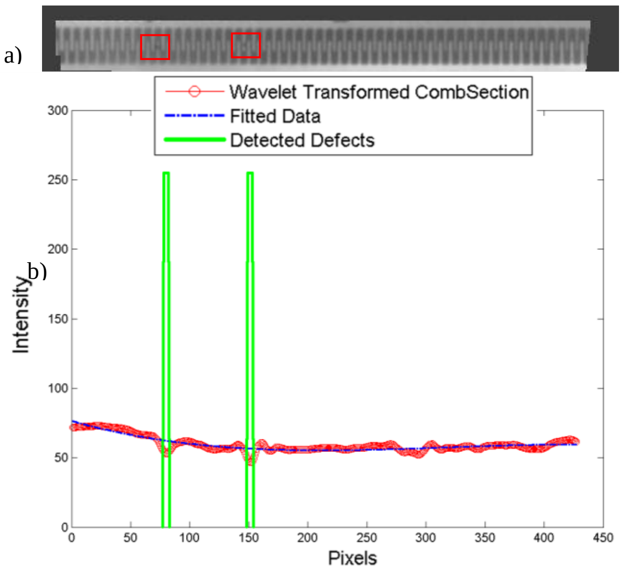


Fig. 11: (a) Segmented combs from figure 9 (contrast enhanced) (b) wavelet analysis with defect.

After the defect detection in the third scale the confocal topographie images are used to characterize the defect, e.g. dust or scratches. Further algorithms for substrate flatness checking and scratch detection have been already implemented and evaluated for micro lens substrates. Their reliability analysis is described in [14].

5. Exemplary results and system performance

The system performance of the presented multiscale measurement system depends on the sensitivity and reliability of the indicator algorithms, the inspection throughput and, on the accuracy of the sensor positioning and the sensor registration accuracy within the machine coordinate system.

The indicator algorithms have been tested on various measurements. It was possible to detect defects with a size of 4 µm in the region of the comb drives which is sensitive enough to detect broken combs and springs. Figure 12 shows a confocal intensity image obtained with a 10x objective lens (fig. 12a) and the zoom into two defect regions (fig. 12b, c). The defects have been measured in detail with a 50x front lens (fig. 12 d-g). In figure 12d the small disruption under 5 µm on a comb is shown, demonstrating the high sensitivity of the indicator evaluation for the 10x confocal scale whose lateral resolution is only approximately 10 µm. To characterize the defects (pollutions and disruptions) in figure 12d and 12e confocal topography information (fig. 12f and 12g) is necessary.

The inspection throughput for a complete waver depends on the number of defects to be characterized during the inspection, the measurement time for every measurement position, the evaluation algorithm time, the field of view planning and the positioning time (table 1).

Sensor	VM (2 MEMS)	CM 10x 1 FOV	CM 50x 1 FOV
Measurement	1 s	8 s	8 s
Image processing	18 s	2.6 s	2,6 s
new FOV planing	8 s	4 s	-

Tab.1: Timetable for different steps during the measurement procedure

In the case of the discussed 3" waver with 72 micro calibration devices each having a size of 8 mm x 8 mm, a single video microscopy measurement is needed for the positions of the comb drive and scratch detection. If we assume 20 indicated FOVs in the second scale, 10 from scratch detection and 10 from the comb drive inspection, and further 20 measurements for possible defects on the comb drives in the complete inspection time per MEMS is around 9 min. In case of the complete waver the inspection time is around 11hours for this example.

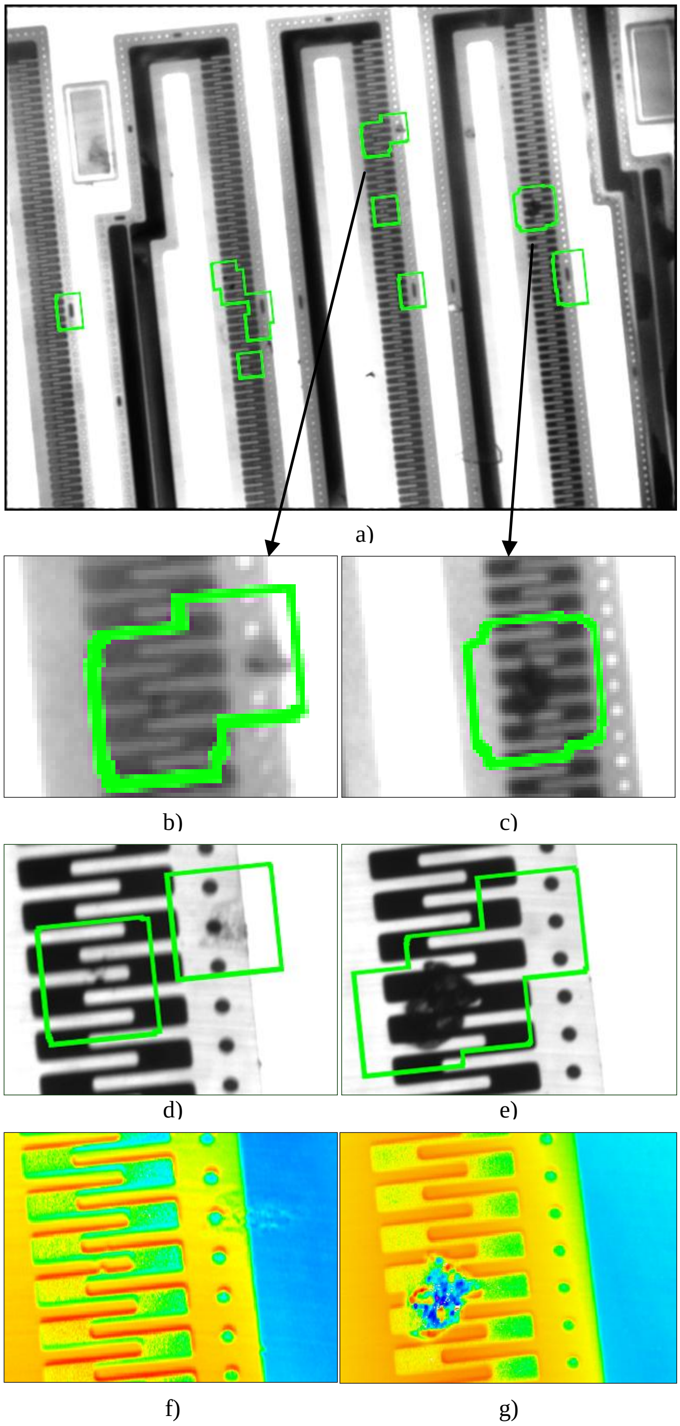


Fig. 4: (a) confocal intensity image taken with 10x, (b, c) digital zoom into two defect indication, (d,e) zoom of defect regions from two confocal 50x measurements and (f, g) corresponding topography images as false color height map.

6. Conclusion

The complete implementation of an automated measurement process for waver level inspection of MEMS with an active exploration strategy has been presented. Furthermore the necessary evaluation algorithms for the automated sensor steering were described. These algorithms are sensitive enough to detect defects near the resolution limit and to enable a feature based communication between different sensors.

The evaluation of the inspection results shows that AMMS can achieve a significant reduction of the inspection time of MEMS wavers.

Further research will deal with the implementation of an assistant system for the automated software and hardware adaption during the measurement process. In addition the strategy has to be implemented for more complex objects like gear drives. To this end, a three dimensional FOV planning and data fusion is necessary.

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