Optimized Parametric Optical Surface Characterization Process for Smooth Engineered Surfaces

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Scattered light measuring techniques enable technical surface characterizations in running production processes. Optimization of the measurement data acquisition process and the transfer of the image processing algorithms to a high performance parallel computing hardware (FPGA) allow high measuring rates.

1 Introduction

Industrial production processes show an increasing demand for in-process surface monitoring of technical parts. Examples are semiconductor industry and metal processing industry with surface finishing processes like grinding, polishing, and rolling. Wear of the manufacturing tool has a strong influence on surface quality (e.g. roughness, structures, etc.) and consequently on manufacturing costs due to part rejections by customers. An appropriate in-process roughness measuring device should operate fast and non-contacting with a variable working distance of at least a few centimeters. In this context, parametric optical scattered light measuring techniques have a high potential for surface inspection applications [1]. In connection with modern electro-optical devices (e.g. high power laser diodes, CMOS cameras) and a high performance parallel computing hardware (FPGA), these speckle techniques show real-time and in-process capabilities.

2 Application

A challenging task is the in-process surface characterization of working rolls from a cold rolling metal forming process. A metal sheet or strip from a coil passes through one or more pairs of working rolls to reduce the thickness and to make it uniform. The rolling process transfers the microstructure of the work rolls to the surface of the metal strip. This produces a variety of surface qualities, from specular reflecting to diffuse scattering. Wear of the work rolls decreases the surface quality of the metal strip. Worn rolls are replaced and reconditioned by grinding, polishing and lapping. The aim is to characterize work roll surfaces during the dressing process completely, and later on to measure the surface roughness of the metal strip in-process near the cold rolling mill with a roughness measuring device based on coherent light scattering and speckle correlations methods.

3 Scattered light measuring technique

Fig. 1 shows the scheme of a roughness measuring system based on the scattered laser light method. A collimated laser beam illuminates the smooth work piece. As the roughness is much smaller than the light wavelength $\lambda = 532$ nm, the surface diffusely reflects the coherent light and produces a partially developed speckle distribution with roughness dependent intensity modulations. Digital processing and evaluation of the speckle patterns quantifies an optical roughness parameter that correlates with the rms surface roughness.

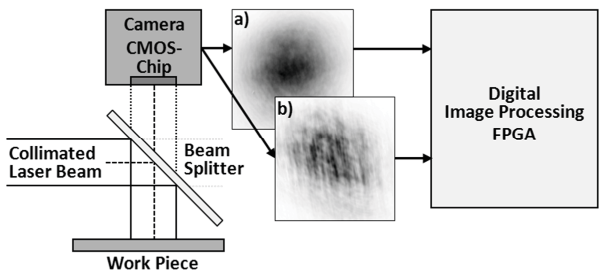

***Fig. 1** Scheme of the roughness measuring set-up and scattered light patterns of surfaces with a) Sa = 3 nm and b) Sa = 12,5 nm.*

4 Measuring process optimization

Current investigations concern the optimization of the measurement set-up and the measuring process with respect to data acquisition at high rates. Measuring process simulations are carried out for measured surface topography data sets and for corresponding model topographies. The calculation of the electromagnetic light wave propagation and scattering is according to the Kirchhoff theory. The implementation of this model includes Fourier transforms of two-dimensional matrices that represent electrical field amplitudes and surface height distributions. Reduction of aliasing and leakage effects requires large lateral matrix dimensions. Fig. 2 shows a measured topography plot of a

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polished surface with 3000 x 3000 points and appropriate dimensions of 6 mm x 6 mm area. The stitched plot is calculated from 50 x 50 single measurements with a white light interferometer with a 20x Mirau interference objective (NA = 0,4). Such extensive measurements are the precondition to compare measured and calculated speckle patterns for same surface areas by more than statistical aspect. This is matter of ongoing investigations in order to optimize the selection of measurement equipment (e.g. laser, optics, and camera).

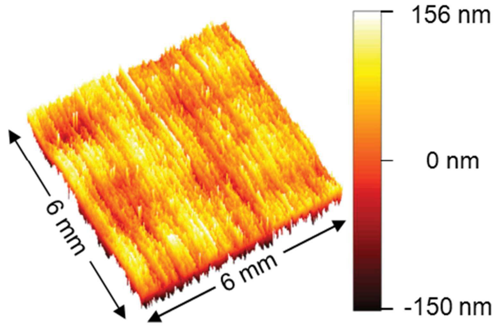

Fig. 2 *Stitched topography plot with 3000 x 3000 points of a polished surface with Sa = 50 nm.*

5 Optimized image processing with FPGAs

The digital image processing and evaluation algorithms are prepared for the transfer to a high performance parallel computing hardware. The speckle image analysis related to surface roughness is based on correlation methods. The consecutive data acquisition at high measuring rates makes image buffering impossible and requires real-time image processing. Therefore, computationally intensive calculations have to be accelerated. In the field of industrial image processing specific hardware architectures offer efficient solutions. High performance embedded systems rely on Field Programmable Gate Arrays (FPGAs), which are energy-efficient, robust, and compact.

The determination of an optical roughness value from scattered light speckle patterns requires the calculation of at least three values of the speckle pattern intensity autocorrelation function (ACF) near to the ACF maximum. Fast Fourier algorithms calculate the complete ACF of the whole speckle image and produce information overhead. Alternatively, the direct calculation of the three relevant ACF values is possible with only multiplications and summations. This method is well suited for data stream processing [2]. The camera sequentially sends pixel values to the calculation unit. The ACF calculation begins once sufficient image rows are buffered and then runs parallel to the ongoing image transfer.

Pipelining enables further optimizations. Similar to parallel processing of image rows, the different algorithm steps operate at the same time. Depending on data availability and computing time, pipelining is possible with consecutive images and with partial results from previous computations. In the end, the image data is processed continuously at the camera speed, i.e. in real time.

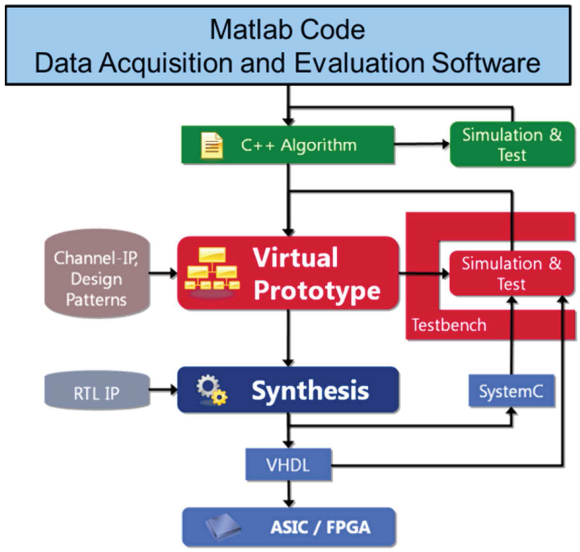

Fig. 3 *Virtual prototype und high-level-synthesis.*

A virtual prototype (Fig. 3) is used for the algorithm development and partitioning in order to ensure an appropriate data flow and to reduce temporary storage and latencies. The first steps of the hardware software co-design can thus be performed with higher programming languages. This allows for efficient development and simulation compared to direct VHDL programming, as being used by standard hardware design methodologies. The applied methodology applies the SystemC simulation library for modelling hardware properties in C++. This leads to an optimized data flow and parallelization of the calculations [3].

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