Dresdner Berichte zur Messsystemtechnik

Herausgeber: Prof. Dr.-Ing. habil. Jürgen Czarske

15

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Laser Interference Sensor for 4D Shape and Vibration Measurement with Camera Based Uncertainty Reduction

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TECHNISCHE UNIVERSITÄT DRESDEN

genehmigte Dissertation

Laser Interference Sensor for 4D Shape and Vibration Measurement with Camera Based Uncertainty Reduction

Hao Zhang

von der Fakultät Elektrotechnik und Informationstechnik

zur Erlangung des akademischen Grades eines

Doktoringenieurs
(Dr.-Ing.)

Vorsizender:	Prof. Dr.-Ing. habil. K.-J. Wolter		
Gutachter:	Prof. Dr.-Ing. habil. J. Czarske	Tag der Einreichung:	27.06.2019
	Prof. Dr.-Ing. habil. P. Lehmann	Tag der Verteidigung:	27.11.2019
Prüfer:	Prof. Dr.-Ing. H. Lakner		

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Shaker Verlag
Düren 2020

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

Zugl.: Dresden, Techn. Univ., Diss., 2019

Printed in Germany.

ISBN 978-3-8440-7237-2
ISSN 1866-5519

Shaker Verlag GmbH • Am Langen Graben 15a • 52353 Düren
Phone: 0049/2421/99011-0 • Telefax: 0049/2421/99011-9
Internet: www.shaker.de • e-mail: info@shaker.de

献给我的母亲

To my mother

Abstract

The measurement of absolute shape, deformation and vibration of fast moving objects for instance turning shafts, rotating workpieces and milling tools in CNC machines is a significant task for the development of manufacturing technology and process monitoring in Industry 4.0. These measurements can be achieved by using the laser Doppler distance sensor with phase evaluation (PLDDS), as the sensor enables simultaneous axial distance and lateral velocity measurement of moving rough surfaces with micron uncertainty and with a single sensor head.

In this dissertation, the PLDDS based measurement technique for the in-situ measurement of absolute 4D shape and tool tip vibration are investigated. The measurement uncertainty and uncertainty budget are investigated with numerical simulation and experiments. It is shown that the achievable measurement uncertainty is limited by the speckle effect and temperature drifts. To overcome the uncertainty limitation due to the speckle effect, a speckle separation technique by using cameras instead of single photo detectors is proposed. Thus, the speckle signals can be detected separately by using a proposed image-processing algorithm and the velocity and distance uncertainty decreases with the square root of the speckle number. A fringe spacing calibration method that can be conducted in-situ is realized to eliminate the fringe spacing uncertainty resulting from temperature drifts. Coherent fiber bundles are employed to forward the scattered light towards the cameras. This removes the cameras from the sensor head and therefore enables a compact and passive sensor head with keyhole access. Compared with a photo detector based sensor, the camera based setup allows to decrease the measurement uncertainty by the order of one magnitude, which is verified by numerical simulations and experimental results. As a result, the absolute shape uncertainty of rotating workpieces can be reduced to about 100 nm.

By extending the measurement volume, a non-scanning, 4D laser line PLDDS is designed. Compared to the conventional PLDDS, the measurement range in a single measurement is increased by a factor of 40. A 4D shape measurement of a rotating workpiece is achieved by employing the proposed sensor without scanning along the rotational axis. This means the sensor can perform simultaneous 3D absolute shape and time resolved deformation measurements at multiple surface segments along the rotational axis. Meanwhile, the measurement uncertainty and position deviation due to mechanical scanning of the sensor are completely avoided.

Moreover, a measurement system for investigating the tip vibration inside of a CNC milling machine under different rotational speeds is developed. It consists of an automated impact unit generating vibrations with a known force and a PLDDS. A signal processing algorithm is proposed. It enables simultaneously bi-directional vibration measurements at non-continuous surface of tool tip with measurement rates up to 50 kHz combined with the measurement system. The dynamic behavior parameters of the tool are estimated depending on the geometric relationship of the displacement in two directions and can be used for machine modelling. Furthermore, the sensor can be used for detecting undesirable milling tool eccentricity, thermal deformation and cutter deterioration in the future.

Acknowledgements

I would like to express my deep gratitude to all the people who supported me to the accomplishment of my doctoral work.

First of all, I want to thank my supervisor Mr. Prof. Dr.-Ing. habil. Jürgen Czarske for his support and guidance as well as the helpful discussions and precious suggestions, which are significant for the accomplishment of the work. I also would like to thank Mr. Prof. Dr.-Ing. habil. Peter Lehmann and Mr. Prof. Dr.-Ing. Hubert Lakner for the willing takeover of my assessment process and examiner.

In these memorable days, it is my pleasure to work with so many outstanding colleagues at the Laboratory of Measurement and Sensor System Techniques (MST) at Technische Universität Dresden. They gave me selfless care and help in the work and daily life. Mr. Dr.-Ing. Robert Kuschmierz is an excellent group leader. I am grateful to him for the valuable suggestions and continued supports. I thank Mr. M. Sc. Julian Lich as well as the ex-colleagues, Mr. Prof. Dr.-Ing. habil. Andreas Fischer and Mr. Dr. Shengyu Shi for the distinguished team cooperation. I also thank all other employees of the MST who are not mentioned above for their supports in completing this exciting work. We shared countless wonderful moments together in these years.

A part of the work is based on the cooperation with the Institute of Mechatronic Engineering of Technische Universität Dresden. For this I would like to thank Mr. Prof. Dr.-Ing. Steffen Ihlenfeldt, Mr. Dr.-Ing. Michael Löser and Mr. Dipl.-Ing. Damian Anders for promoting cooperation, providing the machine for the measurement and conducting the reference measurement.

In addition, I would like to thank Mr. Michael Loeper and his staff from the precision mechanics department of the faculty workshop for their excellent technical support. I especially thank the German Research Foundation and the China Scholarship Council for the financial support of my work as well as German bier and sausages for their supports in my daily life.

Finally, I deeply thank my beloved family members, especially my mother, for sharing the joys and hardships with me, and for giving me unconditional support and encouragement in the exploration.

Hao Zhang

June 2019 in Dresden

Contents