Bioanalysis

Advanced Materials, Methods, and Devices

Volume 9

Series Editor

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The book series on BIOANALYSIS: Advanced Materials, Methods, and Devices is intended to serve as an authoritative reference source for a broad, interdisciplinary audience involved in the research, teaching, learning, and practice of bioanalytical science and technology. Bioanalysis has experienced explosive growth due to the dramatic convergence of advanced technologies and molecular biology research, which has led to the development of entirely new ways to probe biomolecular and cellular processes as well as biological responses to implanted biomaterials and engineered tissues. Novel optical techniques using a wide variety of reporter gene assays, ion channel probes, and fluorescent probes have provided powerful bioanalytical tools for cell-based assays. Fluorescent reporters allow the development of live cell assays with the ability for in vivo sensing of individual biological responses across cell populations, tracking the transport of biological species within intracellular environments, and monitoring multiple responses from the same cell. Novel classes of labels using inorganic fluorophors based on quantum dots or surface-enhanced Raman scattering labels provide unique possibilities for multiplex bioanalyses.

Laser-based technologies are important in the development of ultrasensitive bioanalytical techniques. Lasers are now used as excitation light sources in a wide variety of molecular bioassays. Today, single-molecule detection techniques using laser excitation provide the ultimate tools to elucidate cellular processes. The possibility of fabricating nanoscale materials and components has recently led to the development of devices and techniques that can measure fundamental parameters at the molecular level. With “optical tweezer” techniques, for example, small particles may be trapped by radiation pressure in the focal volume of a high-intensity, focused laser beam. Ingenious optical trapping systems have also been used to measure the force exerted by individual motor proteins.

Whereas the laser has provided a new technology for excitation, the miniaturization and mass production of sensor devices and their associated electronic circuitry has radically transformed the ways detection and imaging of biological species can be performed in vivo and ex vivo. Sensor miniaturization has enabled significant advances in imaging technologies over the last decade in such areas as microarrays and biochips for bioanalysis of a wide variety of species. The miniaturization of high-density optical sensor arrays has also led to the development of advanced high-resolution imaging methods at the cellular or molecular scales. With powerful microscopic tools using near-field optics, scientists are now able to image the biochemical processes and sub-microscopic structures of living cells at unprecedented resolutions.

Recently, nanotechnology, which involves research on and development of materials and species at length scales between 1 to 100 nanometers, has been revolutionizing important areas in bioanalysis at the molecular and cellular level. The combination of molecular nanotechnology and various sensing modalities (optical, electrochemical, etc) opens the possibility of detecting and manipulating atoms and molecules using nano-devices, which have the potential for a wide variety of bioanalyses at the cellular level. These new bioanalytical tools are capable of probing the nanometer world and will make it possible to characterize the chemical and mechanical properties of biomolecules and cells, discover novel phenomena and processes, and provide science with a wide range of tools, materials, devices, and systems with unique characteristics.

This book series will present the most recent scientific and technological advances in materials, methods and instrumentation of interest to researchers, students, and manufacturers. The goal is to provide a comprehensive forum to integrate the contributions of biophysicists, biomedical engineers, materials scientists, chemists, chemical engineers, biologists, and others involved in the science and technology revolution reshaping molecular biology and biomedicine.

More information about this series at http://www.springer.com/series/8091

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Laser Doppler Vibrometry for Non-Contact Diagnostics

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Preface

Cardiovascular diseases are with 40% the most frequent death reason followed by cancer. Many patients realize that they are suffering from heart-circulation diseases in a late state when there is no chance to overcome the disease anymore. An example is atrial fibrillation, which leads to tiredness and lack of activation which mostly is not assumed to be caused by heart disease but by other less dangerous reasons.

Therefore, the idea came up to check the heart functionality every day in the morning and evening when people brush their teeth and stand in front of the mirror in the bathroom. A small box beside the mirror observes the client and measures her or his heart activity by acquiring vibration signals picked up from the human body with a small-size Laser Doppler Vibrometer (vibrocardiogram). If there are no hints for a malfunction of the heart, no message is sent to a health center from where the patient would get help if this is required.

The main advantage of this approach is that the patient does not realize that data are picked up, since in contrast to the well-established electrocardiogram the vibrocardiogram is picked up contactless. Another aspect is that the patient will behave as if no measurement would take place. So she or he is not anxious, stressed, or nervous knowing that data are picked up. To realize this setting, besides the small-size laser Doppler vibrometer a detection system is required to decide whether a person is in front of the system or not. Furthermore, a pan-tilt unit has to track the optimal position for measurement. Since the patient might wear a bathing gown, the best position for measurement might not be a region on the thorax closest to the heart but the neck or throat which is not covered by the gown.

Last but not least, the price has to be affordable for mass consumption. The new device has despite the advantage of contactless measurement to compete in its price with today's available systems for the measurement of the electrocardiogram. This is a quite ambitious challenge for a laser Doppler vibrometer!

Karlsruhe, Germany — Kristian Kroschel
October 2019

Acknowledgements

To write a book is not a project that can be done in only a few days. It was back in early 2018 during the SPIE conference in Strasbourg when Malwina Strenkowska asked me if I would like to write a book for the Springer Nature series on remote sensing of vital parameters of humans using a laser Doppler vibrometer, which was more or less the topic of my presentation in Strasbourg.

Inspired by the presentations of other participants during the conference, I agreed. I was further motivated by initial, very promising results from my student, Laura Mignanelli, who had worked on data which she acquired from the municipal hospital in Karlsruhe. Thanks to the initiative of Christian Rembe, at that time responsible for optics development at Polytec, a well-known manufacturer of laser Doppler vibrometers, a grant was given by the BMBF, the German Ministry of Education and Research, for the Tricorder project under the number 13N13725.

Within this framework, the companies Polytec and Getemed along with three hospitals (Städtisches Klinikum Karlsruhe, University Clinic Mannheim, Charité Berlin) and the Fraunhofer Institute IOSB in Karlsruhe cooperated to develop both, a laser doppler vibrometer for the application mentioned in the foreword and the corresponding software to extract vital parameters including heart rate, heart sounds, and respiration information.

The authors would like to thank the engineers from Polytec, mainly Marco Wolfer, Robert Downes from Getemed who took over the management of the consortium, all employees at the three hospitals involved in data acquisition and Martin Ruckhäberle from the Fraunhofer IOSB, who solved the tedious task of synchronizing measurements and transforming the data into a format for further processing. Deborah Kaska from Santa Barbara, California, also deserves many thanks for her help to improve the writing in English. Last but not least, we would like to thank Smith Chae and his team who transformed the manuscript into this book which is now on the market. We hope all our readers enjoy reading it and that it enhances their research efforts throughout their professional lives.

Karlsruhe, Germany
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The editor and the authors

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About the Editor

Kristian Kroschel is a member of the electrical engineering and communication technology department of the Karlsruhe Institute of Technology. Currently, he is with the Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB and does research in signal processing. He is author of many publications and book chapters on “Laser Doppler vibrometry” and digital signal treatment.