University of California
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High-Speed Imaging and Optical Sensing Systems for Biomedical Applications

A dissertation submitted in partial satisfaction
of the requirements for the degree
Doctor of Philosophy in Electrical Engineering

by

Ata Mahjoubfar

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Abstract of the Dissertation

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Professor Bahram Jalali, Chair

High-throughput real-time optical sensing and imaging instruments for capture and analysis of fast phenomena are among the most essential tools for scientific, industrial, military, and most importantly biomedical applications. The key challenge in these instruments is the fundamental trade-off between speed and sensitivity of the measurement due to the limited signal energy collected in each measurement window. Based on two enabling technologies, namely photonic time-stretch dispersive Fourier transform and optical post-amplification, we developed several novel high-throughput optical measurement tools for applications such as flow cytometry, vibrometry, and volumetric scanning.

We demonstrated optical Raman amplification at about 800 nm wavelength for the first time and extended time-stretch dispersive Fourier transform to this region of electromagnetic spectrum. We used this empowering technology to make an ultrafast three-dimensional laser scanner with about hundred thousand scans per second. Our technique substantially improves the speed of laser scanners by performing an inertia-free scan in one of the dimensions through mapping of that spatial dimension to spectrum and subsequently time and optically amplifying the interrogation optical signals before photodetection to achieve superior sensitivity. The performance of our laser scanner proved to achieve nanometer-scale

axial resolution in measurement of surface vibrations with no need for a feedback stabilization mechanism.

We also employed our high-speed laser scanner to perform label-free cell screening in flow. One of the fundamental challenges in cell analysis is the change in cell behavior induced by the labels, which are used to mark them for better identification. To eliminate the need for cell labeling, while keeping the cell classification accuracy high, additional label-free biophysical parameters such as accurate measurement of the cell protein density is required. We introduced a high-accuracy label-free imaging flow cytometer based on simultaneous measurement of morphology and optical path length through the cell at flow speeds as high as a few meters per second.

Finally, the ultimate challenge in the ultra-high-throughput instrumentation is the storage and analysis of the torrent of data generated. As an example, our imaging flow cytometer generates tens of terabytes of cell images over a course of three hours acquisition, which captures images of every single cell in ten milliliters of sample e.g. blood. We enabled practical use of these big data volumes and velocities by efficient combination of analog preprocessing steps such as quadrature demodulation with parallel digital post processing.

The dissertation of Ata Mahjoubfar is approved.

Dean Ho

Tatsuo Itoh

Kayvan Niazi

Katsushi Arisaka

Benjamin S. Williams

Bahram Jalali, Committee Chair

University of California, Los Angeles

2014

To my parents . . .

who—among so many other things—

got a loan to buy me a computer

when I was in high school

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Acknowledgments

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I would like to thank all of my publication co-authors, which our works consist many chapters of this dissertation. Chapter 1 is a version of Applied Physics Letters, Vol. 98, No. 10, 101107, 2011. Chapter 2 is a version of Proceedings of SPIE, Frontiers in Ultrafast Optics: Biomedical, Scientific, and Industrial Applications

XIII, San Francisco, CA, 2013, 86110N, which is a collaborative work between Prof. Bahram Jalali and Prof. Dino di Carlos groups. Chapter 3 is a version of Biomedical Optics Express, Vol. 4, No. 9, pp. 1618-1625, 2013. Chapter 4 is a version of Journal of the Optical Society of America A, Vol. 30, No. 10, pp. 2124-2132, 2013. Finally, Chapter 5 is a version of Conference on Lasers and Electro-Optics (CLEO), San Jose, CA, 2010, CFA4.

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Vita

1974–1975	Campus computer center "User Services" programmer and consultant, Stanford Center for Information Processing, Stanford University, Stanford, California.
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Publications

MADHOUS Reference Manual. Stanford University, Dean of Student Affairs (Residential Education Division), 1978. Technical documentation for the MADHOUS software system used to assign students to on-campus housing.

CHAPTER 1

Introduction

For text, let's use the first words out of the ispell dictionary.

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