Optical Measurement Techniques in Thermal Sciences - Web course

COURSE OUTLINE

Non-intrusive techniques are being extensively used in engineering measurements. These techniques employ radiation sources as probes. All radiation-based measurements share a common feature in that they generate images of a cross-section of the physical domain.

This is to be contrasted with mechanical probes which are concerned with measurements at a point in space and can accomplish this task only after the field to be studied has been physically perturbed. Radiation methods are also inertia-free. Hence scanning of a cross-section of the physical region using radiation-based probes results in a large volume of information with practically no time delay.

Laser-based optical techniques have reached a high degree of maturity. Optical methods such as laser Doppler velocimetry and particle image velocimetry have replaced traditional methods such as pitot tubes and hot-wire anemometry.

Flow visualization methods of the past have evolved to a point where it is now possible to gain qualitative as well as quantitative understanding of the flow and transport phenomena. Sophisticated measurement techniques such as Rayleigh and Mie scattering for temperature and concentration measurements and Raman spectroscopy for detection of chemical species in reacting flows are routinely employed in engineering research.

Integrating techniques of photography and video recording, digital image processing, optics and color measurement, it is now possible to map the fluid surface slopes of oceans, rivers and lakes optically into a color space.

Using reconstruction techniques, the surface elevations can then be back-calculated. If the fluid surface is relatively flat, the spectrum of the reflected light contains rich information about the temperature variation over it.

Optical methods of measurement are known to have specific advantages in terms of spanning a field-of-view and being inertia-free. Though in use for over half a century, optical methods have seen resurgence over the past decade. The main factors responsible are the twin developments in the availability of cost-effective lasers along with high performance computers.

Laser measurements in thermal sciences have been facilitated additionally by the fact that fluid media are transparent and heat transfer applications in fluids are abundant. Whole-field laser measurements of flow and heat transfer in fluids can be carried out with a variety of configurations: shadowgraph, schlieren, interferometry, speckle and PIV, to name a few.

The ability to record optical images on a PC using CCD cameras has greatly simplified image analysis. It is possible to enhance image quality and perform operations such as contrast improvement, correlations, edge detection and fringe thinning by manipulating numbers representing the image. Image analysis techniques are also covered in the present proposal.

Optical measurements can be extended to map three dimensional flow and thermal fields. Techniques such as holographic interferometry can be cumbersome in some applications due to the need of holographic plates, particularly when large regions have to be scanned. This difficulty is circumvented by using an analytical technique called tomography.

Here the optical images are viewed as projection data of the thermal field. The three dimensional field is then reconstructed by suitable algorithms.

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Mechanical Engineering

Pre-requisites:

1. First course in fluid mechanics and heat transfer.
2. First course in instrumentation.

Additional Reading:

Springer handbook of Experimental fluid mechanics (2007), edited by Cameron Tropea, A.L. Yarin, J.F. Foss

Coordinators:

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COURSE DETAIL

Lecture No.	Topic	Lectures
1.	Introduction, references; Experiments versus simulation. Why conduct experiments.	
2.	Details of an experimental setup: physical domain, probes, measurement system, signal analyzer, computer for data storage and control.	
3.	Nomenclature: errors, uncertainty, sampling, attenuation, phase lag, signal-tonoise ratio.	
4.	A/D conversion: sampling frequency, digitization, influence on s/n ratio.	
5.	Deriving global properties from local measurements. Examples of lift, drag, friction factor, and Nusselt number from velocity, pressure and temperature data.	
6.	Design of experiments; issues related to probe selection. Scaling laws.	
7.	Principles of similarity; Buckingham-π theorem, examples involving Reynolds number, drag coefficient, Strouhal number, and Fourier number. Survey of dimensionless parameters.	
8.	Design of experiments based on sensitivity function and uncertainty analysis. Examples related to (a) determining the duration of the experiment and (b) choosing between steady state and transient techniques. Forward versus inverse measurements.	2
9.	Static and dynamic calibration; compensation in the frequency domain.	
10.	Wind tunnels: open versus closed, low versus high speed; quality parameters.	
11.	Uncertainty analysis, scatter, error propagation formula, central limit theorem, 95% confidence interval, normal and Student's-t distribution, statistical rejection of data, treatment of non-stationary data sets.	2
12.	Review of numerical techniques: curve fitting (regression), integration, differentiation, root finding, solving a system of linear algebraic equations. Examples.	2

13.	Measurement of velocity • Pitot and pitot static tubes (low as well as high speeds), 5-hole probe • Hotwire anemometer, CCA, CTA, 2-wire measurement, turbulent stresses • temperature compensation • Laser Doppler velocimetry • Particle image velocimetry • Analysis of PIV images using cross-correlation technique • Measurement of viscosity	5
14.	Temperature measurement: thermocouples, RTD, thermister, Heat flux measurement, Determination of thermophysical properties.	2
15.	Infrared thermography.	
16.	Introduction to lasers: principle of operation, monochromaticity, coherence, directionality, pulsing features.	
17.	Optical measurement techniques • Interference, interferometry, fringe analysis • Schlieren and shadowgraph techniques • Image analysis using ray tracing technique • Applications (boundary-layers, shocks, natural convection, combustion)	7
18.	Measurements based on light scattering - absorption spectroscopy, shadow formation, Mie scattering, Rayleigh, Raman and other scattering methods.	3
19.	Digital signal and image processing • time series analysis, Fourier transforms • probability density function • auto- and cross-correlations • correlation functions and their use in experiments.	2
20.	Optical tomography • Convolution back projection (CBP) • Algebraic reconstruction technique (ART) • Numerical aspects • Examples	2

References:

1. H.W. Coleman and W.G. Steele Jr., Experiments and Uncertainty Analysis for Engineers, Wiley & Sons, New York, 1989.

2. E.O. Doeblin, Measurement Systems, McGraw-Hill, New York, 1986.

3. R.J. Goldstein (Editor), Fluid Mechanics Measurements, Hemisphere Publishing Corporation, New York, 1983; second edition, 1996.

4. J. Hecht, The Laser Guidebook, McGraw-Hill, New York, 1986.

5. B.E. Jones, Instrumentation Measurement and Feedback, Tata McGraw-Hill, New Delhi, 2000.

6. M. Lehner and D. Mewes, Applied Optical Measurements, Springer-Verlag, Berlin, (1999).

7. F. Mayinger, Image-Forming Optical Techniques in Heat Transfer: revival by Computer- Aided Data Processing, ASME J. Heat Transfer, Vol. 115, pp 824-834, 1993.

8. F. Mayinger, Editor, Optical Measurements: Techniques and Applications, Springer- Verlag, Berlin, 1994.

9. D.C. Montgomery, Design and Analysis of Experiments, John Wiley, New York, 2001.

10. A.S. Morris, Principles of Measurement and Instrumentation, Prentice Hall of India, New Delhi, 1999.

11. F. Natterer, The Mathematics of Computerized Tomography, John Wiley & Sons, New York, 1986.

12. P.K. Rastogi, Ed., Photomechanics, Springer, Berlin, 2000.

13. M. Van Dyke, An Album of Fluid Motion, The Parabolic Press, California, 1982.