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Construction of two dimensional temperature field from first derivative fields

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ABSTRACT

Schlieren and its variants such as differential interferometry and schlieren microscopy, have been used extensively for flow visualization where first derivative fields are captured. The derivative fields obtained from the schlieren like methods can be further processed to estimate the temperature field when the first derivative fields relate to those of temperature. Temperature construction from first derivative field is an ill-posed problem owing to the experimental noise and a few discrete points where measured temperatures may be available. A new approach has been proposed where the domain is discretized into a large number of triangular elements and least-squares based finite-element analysis is performed over the discretized domain. The domain and boundaries are identified manually based on prior knowledge. Temperature fields have been constructed for experimentally obtained first derivative fields from a Differential Interferometer (DI) for different cases. The performance of the new methodology is found to be good.

1. Introduction

Optical methods such as schlieren, interferometry and shadowgraphy have been widely used in visualization of temperature and concentration fields taking advantage of the strong relationship between density (temperature) and refractive index of the medium. Detailed exposition of the development and trends of such methods are available in the literature [1–7]. A classical Schlieren photograph would record a variable intensity field caused by the deflection of light rays passing through the refractive index field [1,2] where the deflection is proportional to the first derivative of density field. A knife edge is used to partially block the optical beam and the orientation of the knife edge decides the direction in which first derivatives are recorded. Therefore by measuring the intensity variations, first derivative field can be estimated quantitatively. Background oriented schlieren (BOS) and calibrated color schlieren (CCS) [8] are offshoots of classical schlieren where first derivative data are recorded in more than one direction simultaneously. A Differential Interferometer (DI) [9–13], also referred to as shearing or schlieren interferometer in the literature, constructed from the classical interferometry techniques, records fringe field which is related to the first derivative along one direction of the scalar variable. The measurement of phase field [11,13] of the interferogram facilitates quantitative estimation of first derivative field. It should also be mentioned that *schlieren like* methods have been used extensively for surface profiling, strain measurement [14] and optical testing (lateral shearing interferometers) [15–18].

All these methods, referred to as *schlieren like* methods henceforth, capture quantities such as phase, intensity (gray or color) stored in each pixel of the photograph, from which first derivative of scalar field such as temperature, concentration, density and displacement can be quantified. The advantages of *schlieren like* methods over classical interferometry techniques such as Mach-Zehnder and Michelson is simple optical construction and low sensitivity to external disturbance. Also, heat flux from surfaces can be directly estimated using *schlieren like* methods [12,13,19]. Nevertheless, estimation of temperature field would throw light on nature of the flow and thermal fields. Most of the *schlieren like* methods record derivative fields along only one direction at a given instant. Differentiation of a scalar field along one direction results in loss of information in the orthogonal direction, making reconstruction of scalar field from a single derivative field ill-posed. If temperature construction has to be performed for steady physical domain, the derivative fields can be captured along two directions independently. However, for a transient field, scalar field has to be constructed from a single derivative field.

The present paper addresses the construction of scalar refractive index and hence temperature field from temperature derivative field(s) recorded from one of the many schlieren like methods. A finite-element method has been developed to estimate the temperature field from first derivatives for the entire domain. The method has been tested with experimental interferograms captured from a DI.

2. Optical setup

The core element of the DI is the Wollaston prism which is a shearing element. The Wollaston prism consists of two birefringent

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