Neural-Net Based Modeling of Velocity and Concentration Fields

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Abstract: This paper proposes a novel algorithm using an artificial neural network for modeling simultaneously both a 3-D flow velocity vector and a concentration field. The neural network is trained so that four outputted values of the network, three components of a 3-D velocity vector and a concentration of substances such as air pollutants or bacilli, agree with measured ones and additionally the continuity and diffusion equations are satisfied in the flow field. An approximate model for the velocity and concentration field can be constructed in the neural network from sparsely measured data. When any 3-D position, (x, y, z), is inputted to the neural network model, it outputs a 3-D velocity vector and a concentration at the position. The entire 3-D velocity vector and concentration field, therefore, can be easily estimated using the model. To validate the algorithm, the smoke concentration distribution estimated from a very limited set of measured data is compared with the measured one in which most of the data is unused for the modeling. Even from sparsely measured velocity vectors and smoke concentrations, the novel algorithm gives the entire concentration distribution whose flow characteristics are almost similar to the experimental result.

Keywords: Modeling of Flow Fields, Neural Network, 3-D Velocity Vector, Concentration

1. Introduction

Although 3-D velocity, concentration and temperature fields can be measured in a laboratory (Reungoat et al., 2007; Fujisawa et al., 2008), the whole flow field measurement is very difficult in a real space such as a hospital room, which is always occupied by patients, or a domed baseball stadium, which has a large volume. Airflow distributions are usually measured with some sensors whose measured points are limited in the 3-D space. It is required, therefore, to estimate the entire velocity vector field from sparsely measured data. If some contaminant is contained in the space, the entire concentration distribution should also be estimated. One promising approach for the estimation is to make an appropriate model of the entire field by using some known quantities such as measured data and boundary conditions. Of conventional estimation methods for flow fields, the MASCON (Mass Consistent method) (Dickerson, 1978), which has been very popular in meteorology, and the CFM (Cost Function Method) (Shiota et al., 2000) have been proposed for correcting measured data and interpolating them at the data-lacking points. In those methods, the cost function is minimized by calculus of variations so that the governing equations such as the continuity and Navier Stokes ones are satisfied in the field and also the velocity vectors adjusted according to each algorithm fit the observed (measured) ones.

We present another novel algorithm using an artificial neural network for modeling the 3-D flow velocity vector and concentration field. It is well known that neural networks are excellent tools for realizing ‘non-linear smooth mapping’. The neural networks do not require many data for the mapping because they make an
appropriate model by using not a dependent variable as a velocity vector itself but an independent one as a synaptic weight. By introducing some knowledge on characteristic properties such as the mass conservation of air and pollutants (equations of continuity and diffusion), the neural networks can realize effectively an accurate approximation of the velocity and concentration field. In this paper, the neural-net based algorithm is actually applied to an airflow field in the full size model of an infection-free hospital room to evaluate its air purification performance. A smoke diffusion experiment is carried out by using smoke-emitting incense sticks. Velocity vectors and smoke concentrations are measured with a three-dimensional ultrasonic anemometer and a particle counter, respectively. An approximate model for the velocity and concentration field is formed in the neural network from sparsely measured data on velocity and smoke concentration, which are very small in number, and its boundary conditions. The model additionally satisfies the continuity and diffusion equations. The entire 3-D velocity vector and smoke concentration distributions are automatically outputted by inputting all the positions \((x, y, z)\) in the space to the constructed neural-net model. The estimated smoke concentration distribution in the room is compared with the measured one in order to validate the modeling.

2. Neural-Net Based Modeling

![Fig. 1 Neural-net algorithm by 'model inclusive learning']

We propose a novel algorithm using an artificial neural network for modeling the 3-D flow velocity vector and concentration field as shown in Fig. 1. The neural network receives a position vector, \(\mathbf{x}(x, y, z)\), and outputs a vector potential, \(\mathbf{A}\), and a concentration, \(c_e\). The relationship between the vector potential, \(\mathbf{A}\), and the estimated vector, \(\mathbf{v}_e\), is defined by

\[
\mathbf{v}_e = \text{rot} \mathbf{A}
\]  

The continuity equation of flow, therefore, is automatically satisfied as follows.

\[
\text{div} \mathbf{v}_e = \text{div} (\text{rot} \mathbf{A}) = 0
\]