Building and Environment 118 (2017) 184–195

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Inverse identification of multiple temporal sources releasing the same tracer gaseous pollutant

Yun Wei [a], Hongbiao Zhou [b], Tengfei (Tim) Zhang [a, *], Shugang Wang [a]

[a] School of Civil Engineering, Dalian University of Technology (DUT), 2 Linggong Road, Dalian 116024, China
[b] The Third Railway Survey and Design Institute Group Corporation, Tianjin, China

ARTICLE INFO

Article history:
Received 2 January 2017
Received in revised form
15 March 2017
Accepted 18 March 2017
Available online 20 March 2017

Keywords:
Inverse model
Multiple sources
Temporal release
Rate profile
CFD

ABSTRACT

When an accidental release of indoor airborne pollutants occurs, it is critical to promptly identify the pollutant sources. Current inverse models concentrate on the identification of a single pollutant source or multiple pollutant sources in a simplified puff or constant release scenarios. This investigation proposes an inverse model to precisely determine the locations and temporal release rate profiles of multiple sources releasing the same tracer gaseous pollutant. The model first constitutes a number of candidate group sources by assuming known release positions. Then Tikhonov-based matrix inversion is implemented to solve for the release rate profiles of each candidate group of sources. The concentrations provided by the sensors in the same number of the isolated sources are the known inputs for the matrix inversion. As for the multiple candidate group sources, the occurrence probability of each group is determined by the Bayesian model after matching the concentration with one additional sensor. The above strategy was applied to identify the same pollutant accidentally released by two passengers in a three-dimensional aircraft cabin. The pollutant was from the exhalation points and discharged in an intermittent sinusoidal wave and a square wave of ten seconds, respectively. The results show that the proposed method can correctly determine the locations of multiple temporally released sources. The relative errors between the inversely identified release rates and the CFD-simulated actual rates are generally less than 15%.

1. Introduction

If an accidental release of indoor airborne pollutants occurs, it is critical to promptly identify the number of released pollutant sources, their locations, and the temporal release rates. Then emergency actions can be appropriately taken to protect the indoor occupants from being harmed. Current sensors can tell the temporal concentration locally but cannot tell where, when and how the pollutants have been released. Inference of the pollutant sources based on the limited available concentrations constitutes inverse modeling.

Indoor airborne pollutant releases are complicated. The pollutants can be released anywhere, anytime, and at any release rate. The pollutant release can be from a single source or multiple isolated sources. If multiple sources emit the same pollutant, the monitored concentration at a sensor is the superposition of concentrations from each source. The inverse modeling must decouple the combined concentration response into that from each source to determine the pollutant sources. Therefore, inverse identification of multiple simultaneously released pollutant sources is more challenging.

Fortunately, some pioneering studies started to identify multiple sources, though the dealt cases were over simplified. For example, Bady et al. [1] and Liu et al. [2] implemented the reversed time-marching method to identify multiple sources, but only the source locations were determined, and the sources were prescribed to fixed constant rates. Girault et al. [3] estimated the release rates of two pollutant sources using a reduced model that linked the monitored concentrations with source rates. However, the source locations must be known a priori. Cai et al. [4] determined multiple constant release source locations and emission rates by matching concentrations. There is still no inverse model that can identify multiple pollutant sources with temporally varied release rates.

Despite limited research on multiple sources, there are studies on the identification of a single pollutant source [5]. The identified variables include the source location, temporal release rate, and

* Corresponding author.
E-mail address: tzhang@dlut.edu.cn (T. Zhang).

http://dx.doi.org/10.1016/j.buildenv.2017.03.026
0360-1323/

Nomenclature

A	linear matrix that describes the cause-effect relationship between the release rate and the exhibited pollutant concentration, ppm·min/l
c	temporal pollutant concentration, ppm
c	concentration vector, ppm
C	concentration matrix, ppm
c_O	observed concentration measured by a sensor, ppm
c_{G_m}	predicted concentration at the sensor's location for a candidate group of sources G_m, ppm
F	concentration response of a unit impulse release, i.e., response factor, ppm·min/l
G	candidate group of sources
$L(O\|G_m)$	likelihood of acquiring the measured observation O for the candidate group of sources G_m
L	regularized matrix, ppm·min/l
M	total number of candidate groups of sources
n	total number of isolated pollutant sources
O	measurement observation
$p(G_m)$	prior probability of a candidate group G_m as the source
$p(G_m\|O)$	probability of a candidate group G_m as the actual sources based on the observation O
q	temporal release rate of a pollutant source, l/min
q	temporal release rate vector, l/min
Q	temporal release rate matrix, l/min
t	time, s
u	air velocity vector, m/s

Greek variable

$\delta(t-\tau)$	unit impulse release at time $t = \tau$
Γ	effective mass diffusion coefficient
λ	regularized parameter
ρ	air density, kg/m^3
σ^2	differentiating error variance between the observed and the predicted concentrations, ppm
τ	time, s

Subscript

i	index of pollutant source location
k	index of time step
l	total number of time steps
m, s	index of a candidate group of sources

Superscript

j	index of sensor

sensor alarm time. Determination of a pollutant source location is the most commonly investigated parameter. The adopted strategies can generally be divided into two categories, namely, directly reversing transport equations to track a source and solving forward transport equations to match a source. For example, Zhang and Chen [6] applied the first strategy and solved a quasi-reversibility (QR) equation to identify a pollutant source location via directly reversing the time-marching direction of the pollutant transport equation. The QR method was further extended to locate a particulate source after accounting for the gravitational settling effect [7]. Solving the convective transport of pollutant in a reversed flow field with the pseudo-reversibility method can also locate a pollutant source [8]. The first strategy does not require extensive a priori source information but may suffer from numerical instability.

Most researchers turn to the second strategy, which is numerically stable. If a candidate source is found to be providing concentration responses highly comparable with a monitoring sensor, it is determined to be the source. Liu and Zhai [9,10] solved the adjoint equation of pollutant source location probability to determine a single gaseous source location. Vukovic et al. [11] and Bastani et al. [12] applied neural networking to match the pollutant source concentration and find a source. Thomson et al. [13] searched for a source by minimizing a cost function. Wang et al. [14] matched a source with the concentration response provided by the state-space matrix. Li et al. [15] proposed to use two nondimensional indices, response coefficient to supply air (RCSA) and response coefficient to contaminant source (RCCS) to help judge the position of a source. However, the second strategy may impose significant computing expense when solving and matching concentration. All possible source information, including the release location and temporal rate profiles, must be assumed to be known in advance.

In addition to pollutant source locations, some studies also addressed identification of pollutant release rates. A linear scaling method [8] was utilized to determine the total amount of an instantaneously released source. However, for a temporally released source, the linear scaling method is invalid. Zhang et al. [16] proposed a matrix inversion method to determine the temporal release rate profile of a gaseous source, using the monitoring concentration at a sensor as the known input. A regularized technique [17,18] was adopted to reduce the ill-posedness of the inverted matrix to obtain a converging solution. In the investigation [16], the pollutant source location must be known.

For more comprehensive source information, it is necessary to identify both the pollutant source location and its temporal release rate profiles simultaneously. Sohn et al. [19] applied a Bayesian model to predict the location and quantity released for a single pollutant source. All candidate pollutant source locations and release rates were presumed to be known. Sreedharan et al. [20,21] applied a similar method to determine a source location and its release magnitude, when optimizing a sensor network for pollutant source detection. Recently, Zhang et al. [22] combined an inverse matrix operation with a Bayesian probability model to identify a pollutant source location, temporal rate profile and the sensor alarm time. The required inputs are temporal concentrations at two different sensors in a space.

The above review reveals that current inverse models can comprehensively identify a single pollutant source but have difficulty in identifying multiple temporally released pollutant sources. The large number of inverse studies resolving a single pollutant source provided insights for the more challenging problem of multiple pollutant sources. Extension and modification of the current inverse models for multiple sources are the objectives of this investigation.

2. Methodology

This section addresses the basic principles of identification of multiple pollutant sources releasing the same tracer gaseous pollutant temporally in a fixed flow context. The governing cause-effect relationship of multiple pollutant sources is presented first, followed by the inverse methodology to determine the temporal release rate profiles and the locations of sources.