Pollutants Transfer Simulation Model using Combination of AR and CFD Techniques on Cell Phone Platform

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ABSTRACT

Engineering problems are generally mathematical models of physical phenomena. The solution of the physical problem can be found using engineering and simulation approaches such as numerical modeling. Augmented reality technology adds virtual content created by a computer or mobile phone with a camera to the physical environment of users. Using an augmented reality-based system, after analysis, the simulation results can be placed directly on real-world objects in a two or three-dimensional model corresponding to the location and dimensions of the physical body in order to better understand the results. In this research, using a combination of augmented reality and computational fluid dynamics techniques, a simulation model in an indoor environment with different pollutants has been developed. For this purpose, first, the basic concepts of augmented reality are expressed and its differences with virtual reality are examined. After examining the implementation method of the proposed model, the results for carbon dioxide and carbon monoxide pollutants have been obtained. To evaluate the proposed model, the data obtained from the mobile software are compared with the related benchmark results and show the relatively good accuracy and computational capability.

KEYWORDS

Augmented Reality, Computational Fluid Dynamics, Air Flow, Pollutant Diffusion, Data Visualization.

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1. Introduction

Augmented reality has become an important research topic worldwide in recent years. Augmented reality technology adds computer-generated content such as sound, video, and graphic effects to users' physical environment. The integration of augmented reality with numerical simulation provides a cognitive and scientific method for users to analyze practical problems. Using scientific visualization technologies, an augmented reality-based system, engineering analysis and simulation results are obtained directly on real-world objects. Integrating computational fluid dynamics simulation results with augmented reality enables simulation results to be directly applied to the real world after engineering analysis.

In order to renovate the building, Fukuda et al. have developed an internal thermal environment design system using augmented reality and have used green space inside the building as a renovation method to improve the thermal environment [1]. John and Moreland have combined augmented reality with computational fluid dynamics and presented a tool for training the operation of a big boiler of a coal power plant [2]. In order to understand the internal thermal environment, Lin et al., have developed a tool that displays the results of computational fluid dynamics simulation using augmented reality on a mobile phone. To improve the performance of the developed tool, an integrated approach based on the client-server framework is developed [3]. Solmaz et al., have combined computational fluid dynamics with marker-based augmented reality and presented an application for training the mixing process inside the tank [4].

Recently, engineering analysis and simulation software are seeking to provide an easy user interface. The post-processing part in simulation platforms plays an important role in converting raw data into meaningful concepts for designers and engineers. The possibility of displaying data in a real environment is considered as an indicator feature in the post-processing process, which is realized by augmented reality. In this research developed a software platform on a mobile phone which can simulate and display the results with the augmented reality technique in the same mobile phone space. Transferring the calculations to the mobile device and finally displaying the results on the object is one of the important features of the present research.

2. Simulator model of pollutant transfer

For simulation of pollutants transfer into continuous media, the unsteady mass transfer equation is used. This equation can be model the pollutant transfer over time with different physical characteristics of the related mass. This equation in general form and for pollutant transport into the environment contains fluid, is as:

$$\frac{\partial c}{\partial t} + (U.\nabla)c = D\nabla^2 c + S \tag{1}$$

where, U is the velocity, c is the concentration, D is the mass diffusion coefficient of the substance and S is the mass production term (source specifications if any). The unsteady mass transfer equation includes spatial and temporal expressions, which can model concentration variations into time and space directions. Solution of the governing equation requires numerical approaches which discretize spatial and temporal expressions. For the discretization of the spatial terms, the second-order central differencing scheme was used, and the time integration was performed using the explicit forth order Runge-Kutta method.

3. Problem geometry and boundary conditions

The intended area for experiments is a room of a residential house. The three-dimensional geometrical model of the room is generated as shown in Fig. 1. Windows and doors are closed during the experiment. To determine the boundary conditions corresponding to the real conditions, no concentration penetration has been used for all faces. To simulate the concentration of pollutants over time, a point source of pollutant with a certain concentration is defined at the bottom of the model. In fact, on the floor of the room in the part where the source is located, the concentration is equal to a certain value and for other points, the derivative of the concentration in the direction perpendicular to the face is equal to zero.

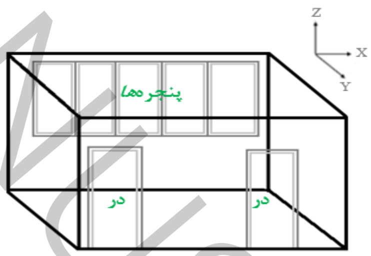


Figure 1. Schematic of the investigated space.

4. Results

To model pollutant transfer in the indoor environment, a simulation software has been developed in Android environment. Mobile software includes three stages: pre-processing, processing and post-processing. In the preprocessing stage, the dimensions of the environment are measured, and the related geometry is generated. In the processing part, using the data obtained from the previous step, equation (1) is solved on all mesh points by mobile phone according to the related initial and boundary conditions. In the post-processing stage, the distribution of the concentration is plotted and reported. Finally, by using the augmented reality technique and the marker-based tracking method, the results of the simulation are displayed on the real environment by the mobile phone camera.

In the present study, the simulation of carbon dioxide and carbon monoxide transfer in the environment of a room with the dimensions of 4.3 × 3.5 × 2.5 meters has been performed. The number of grid points along the horizontal and vertical axes is equal to 30 and in the transverse direction is equal to 20. The source of pollutant is assumed to be a heater, in addition to emitting heat, also emits carbon dioxide and carbon monoxide in the air. To start the solution of the governing equation, an initial value which is equal to one is considered for the pollutant source. In addition, the increase of the horizontal and vertical component of the fluid velocity vector v has been considered. The simulation of the pollutants transferring for a certain time of 400 and 500 seconds and by a time step size of 0.01 seconds has been done in real time.

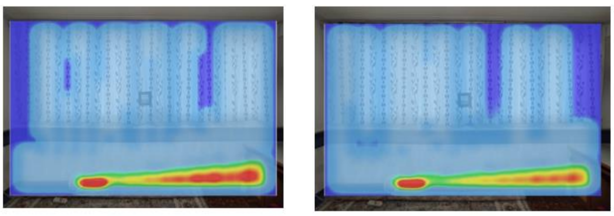
Figures 2 and 3 respectively show the contour of the concentration of carbon dioxide and carbon monoxide pollutants in an indoor environment on a mobile phone using augmented reality. The physical properties of the continuous field for carbon dioxide pollutant are listed in Table 1 and for carbon monoxide pollutant are shown in Table 2.

Table 1. Physical properties of the flow field for carbon dioxide pollutant.

	Time Period (s)	Horizontal velocity (m/s)	Vertical velocity (m/s)	Lateral velocity (m/s)
A	400	0.015	0.0025	0
B	500	0.02	0.003	0

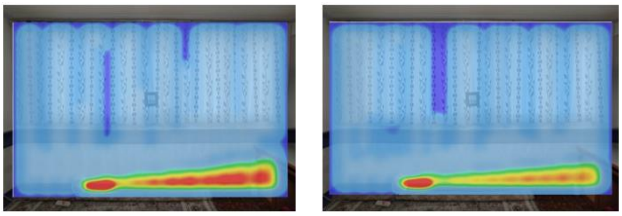
Table 2. Physical properties of the flow field for carbon monoxide pollutant.

	Time Period (s)	Horizontal velocity (m/s)	Vertical velocity (m/s)	Lateral velocity (m/s)
A	400	0.013	0.0024	0
B	500	0.017	0.0027	0



A B

Figure 2. The results of simulation the emission of carbon dioxide pollutant in an indoor environment on a cell phone and by using augmented reality



A B

Figure 3. The results of simulation the emission of carbon monoxide pollutant in an indoor environment on a cell phone and by using augmented reality

5. Conclusions

By enabling interaction between virtual and real worlds, augmented reality creates a new paradigm and easy user interface for understanding physical phenomena. For this reason, in this research to model the transfer of pollutants in the indoor environment, the combination of augmented reality techniques and computational fluid dynamics have been used to develop mobile phone software to simulate the transfer of pollutants in a certain time. this software includes three stages of pre-processing, processing and post-processing. In this research, the simulation of the transfer of carbon dioxide and carbon monoxide pollutants in the air with changes in the flow rate has been done. Comparing the results of the developed software with the data from the validated code [5], shows the accuracy of the developed module for simulating the transport of pollutants in an indoor environment.

6. References

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