Web-based forecasting system of airborne livestock virus spread simulated by OpenFOAM CFD


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Abstract

Livestock infectious diseases including foot-and-mouth disease (FMD) and highly pathogenic avian influenza (HPAI) can make a numerous economic damage to livestock industry. Among various causes for disease spread, airborne spread is difficult to control by previous disease preventive measures that focus on direct and indirect contact. Airborne virus moves through invisible airflow, and field experiments are ineffective due to rarefied concentrations of virus in the air and limitations on measuring techniques. Therefore, a modelling technique for airborne virus spread is important to make counter-measures and strategies against disease outbreak that can be used for farm workers and policy decision makers. Forecasting airborne virus spread is therefore more important than epidemiological investigation after outbreaks of livestock disease. In this study, OpenFOAM CFD code that was provided in a free license was used to simulate airborne virus spread. For real-time forecasting for next 48 hours, weather forecasting data from the Korea Meteorological Administration (KMA) was directly connected in the simulation model every three-hour interval. To save computation time, scalar transport for virus spread was conducted by using the airflow database that was previously simulated under representative wind conditions in research site. The simulation results were used to make the web-based forecasting system that provides airborne virus spread, weather forecast, and livestock farm information.

Keywords: aerosol, computational fluid dynamics, foot-and-mouth disease, GIS, OpenFOAM

1 Introduction

The outbreak of livestock infectious disease makes a lot of economic damage to farm and government. There is an urgent need to minimise this livestock infectious diseases based on the preventive measures at the beginning of outbreak. The spread of livestock infectious diseases could not be blocked due to various transmission routes. Becuase the airborne spread of livestock disease could not be considered for preventive measures due to a lack of information. The preparation of a counterplan has been required to make effective preventive system against contact transmissions but also in airborne transmission.

There are three factors on livestock virus spread; 1) direct contact from infected animal, 2) indirect contact by infected objects, and 3) airborne spread through airflow (Weber et al., 2008). Most of the preventive measures have been focused on blockade of virus transmission without consideration of airborne transmission. However, there are many
difficulties on field experiments including a lack of basic information on airborne virus spread, incubation period, detection problem, and delayed declaration from farm manager.

Aerodynamics simulation models have arisen to predict the airborne virus spreading route (Mayer et al., 2008; Krumkamp et al., 2008; Seo et al., 2013). Recently computational fluid dynamics (CFD) has been widely used to solve aerodynamic problems. Compared to the Gaussian-based simulation models, CFD can be used to specific airflow analysis, considering complex topographical information and related facilities in a local area that has a concentration of livestock farms (Hong et al., 2012, Seo et al., 2013). CFD can simulate airflow patterns and aerosol dispersion based on complex topographical information and environmental factors.

Information on airborne virus spread should be used for emergency preventive measures against livestock disease outbreaks. The estimation and forecasting of airborne virus spread are required to make time to prepare for farmers and government officers. Therefore, a real-time forecasting model of airborne spreading tendency with real-time weather forecasting information is highly required before outbreak of livestock infectious disease. The predicted airborne spreading route can be provided for research and public purposes. This system can play an important role for effective strategy of preventive measures by means of a rapid warning system against the possibility of livestock infectious disease through airflow.

The objective of this paper is to build a main structure for a prediction and forecasting system of airborne livestock disease spread to prepare and manage the risk of airborne virus spread according to weather conditions by using airborne livestock virus characteristics, OpenFOAM CFD tool, GIS information, weather database, and web-based information providing system.

2 Materials and methods

Research Site was selected by Anseong area where suffered by FMD outbreak in 2002 based on reviewing the epidemiological investigation of FMD outbreaks in Korea with cooperation of the Animal and Plant Quarantine Agency (APQA) (Figure 1). The Anseong research site has a clear spreading pattern during 2002 FMD outbreak, which can be effectively used for airborne spread model validation.

Weather data was collected from five AWSs (Automatic weather stations) operated by the KMA (Korea meteorological administration): Baegam (E 37.1618° N 127.3816° 126 m), Moga (E 37.1691°, N 127.4823°, 92 m), Iljuk (E 37.0906°, N 127.4770°, 84 m), Anseong (E 37.0087°, N 127.2672°, 36 m), and Bogae (E 37.0197°, 127.2919°, 82 m in elevation). An additional weather station was installed in a flat area where it is rare to have vehicle movement, and there are no obstacles within a distance of 10 m (E 37.0807°, N 127.4469°, 105 m).

Open field operation and manipulation (OpenFOAM, version 2.1.1.) was used in this research among the various CFD codes. OpenFOAM has no license cost for research as well as commercial purposes. OpenFOAM, which was developed by an object-oriented program system under LINUX OS and the C++ program language, has advantages in terms of cost reduction, expandability of hardware scale, reduction in computation time, simplicity in adding functions, and production of a private program. However, OpenFOAM is still difficult to make a simulation codes based on the text user interface. OpenFOAM was used to make an integrated total solution package for airborne virus spread, including complex topography modelling, airflow analysis, and virus spread analysis.

Figure 2 shows a flowchart to make a web-based livestock disease information providing system which can provide farm information, livestock disease information, and airborne virus spread interworking CFD simulation and real-time weather forecast. The research procedure can be divided into five steps; 1) development of CFD simulation model predicting airborne
virus spread using OpenFOAM, 2) construction of the weather data acquisition server using AWSs and the weather station, 3) derive of a virus emission calculation algorithm with considering animal species, livestock houses characteristics, and numbers of animals, 4) construction of integrated server system for inter-working real-time weather information and CFD simulation using OpenFOAM, 5) service of a web-based livestock disease information providing system for supporting an airborne virus spread pattern.

3 Results and Discussion

Three dimensional topography modelling was conducted to make CFD simulation model using GIS as shown in Figure 2. Complex topography was designed from a numerical map with 1:25,000 scale provided by the Ministry of Land, Infrastructure and Transport in Korea. The modelling was conducted by extracting a contour map, creating a triangular irregular network (TIN), and converting to a digital elevation model (DEM). The three-dimensional airflow pattern and airborne virus spread were simulated by 1) unsteady simulation for tracking the virus spread route time-dependently, 2) turbulent analysis for turbulence effect due to complex topography, and 3) scalar transport analysis for predicting the airborne virus spread.

Database system for weather information was constructed on predicting airborne livestock disease spread. Hourly meteorological observations were collected by wireless modem using the code division multiple access (CDMA) technique; then, it was saved to a database management server using DB input programs (Figure 3). The climate and weather data were also used for the web-based livestock disease information providing system by changing its format to be suitable for the website. Korea meteorological administration operates an automatic weather observation network, including 464 AWSs and an observed weather database that collects hourly observatory data. In addition, KMA releases weather forecasts for 48 hours at every three-hour interval, including the air temperature, relative humidity, and probability of precipitation at 12-hour intervals.

The CFD computed airflow was validated by comparing between observatory data by AWSs and the installed weather station during relatively stable wind conditions. The reason is that the CFD model computes steady-state conditions which is not common in real situations. Continuously changing the wind speed makes changeable airflow pattern from the inlet boundary to the outlet boundary. Therefore, meteorological measurement for different locations at the same time was inappropriate for validating the CFD simulation model at the steady-state condition. The CFD computed wind directions at each observation location were shown the similar wind directions under wind directions separated by 16 parts. And the difference in the average wind speed between the CFD computed and AWS measured airflow showed an error of 11.6 %, which is reasonable data for the CFD validation when considering the size of the computational domain.

The algorithm for FMD virus emission rate was suggested by a combination between virus-based scientific information and field-measured aerosol concentration as shown in Figure 4. The emission rate was calculated by considering animal, livestock house, and farm operation characteristics. Then, the value was used as input generation concentration at the point sources for each livestock house. The equation includes the livestock aerosol concentration according to the animal species, ages, and floor types in accordance with the database table, number of animals in the infected livestock farm, recommendation of livestock density, time interval for CFD simulation, and infection ratio.

Real-time CFD simulation was computed by interworking with real-time weather forecasting. Ground surface modelling using complex topography and a database for airflow patterns according to various wind directions and speeds was prepared to make a database. Using the database, the real-time scalar transport simulation for airborne FMD disease spread modelling has been conducted every three-hour interval for the subsequent 48 hours through three routine processes by interworking with weather forecasting. There was three main
steps for simulation; 1) database construction for weather forecasting, 2) CFD simulation of virus scalar transport using time-dependent airflow pattern database, and 3) forecasting the web-based airborne livestock disease spread information providing system.

The web-based livestock disease information-providing system was developed to provide livestock disease-related information from the constructed observed weather database as shown in Figure 5. Weather data during certain periods required by users can be retrieved in table form. The prediction of airborne virus spread was provided in an animation form with time-dependence over the GIS map, including the administrative district map, road map, terrain map, and satellite image, with super resolution of 5 m as a background layer by means of the WebGIS technique. The prediction of airborne virus spread was provided by a web-map interface, as shown in Figure 6. The animation was created during the next 48 hours with thirty-minute intervals based on the weather forecasting from KMA. The concentration of livestock disease virus and its spreading route through airflow patterns from infected farms can be expressed in a time-dependent way.

4 Conclusions

The web-based livestock disease information-providing system (WDIPS) was developed as a commercial solution for investigating epidemiological interrelationships between livestock infectious diseases and weather conditions and to set up a prediction technique using computational fluid dynamics (CFD). The WDIPS can predict airborne virus spread during the next 48 hours based on the real-time weather forecasting supported by the Korea meteorological administration (KMA). Stored data can be used for user-friendly web-based services to make preventive measures and farm management strategies against livestock infectious diseases. The WDIPS can be utilised for other livestock infectious diseases by means of a minor adjustment of the input environment and flexible criteria that are suitable to other animal species. In the future, the weather information service should be expanded to the biome-eteorology industry, and information concerning airborne virus spread can be used to reduce damage from livestock infectious diseases by predicting the routes used for virus spread.

5 References


Figure 1: Satellite image in the Anseong research site with locations of research livestock farms.

Figure 2: Process of web-based information system

Figure 3: Flow chart for the construction of the climate and weather information database
Figure 4: Algorithm for the calculation of the FMD virus emission rate

Figure 5: Information tree provided by warning system for airborne spread of livestock viruses

Figure 6: A sample image for airborne spread of livestock viruses (http://livestock.ncam.kr/en/contents/menu1-1.php)