Environmental Modelling & Software 91 (2017) 111–126

Contents lists available at ScienceDirect

Environmental Modelling & Software

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

An integrated flood management system based on linking environmental models and disaster-related data

Linyao Qiu [a, d], Zhiqiang Du [a, d, *], Qing Zhu [a, b, c, d], Yida Fan [e]

[a] State Key Laboratory of Information Engineering in Surveying Mapping and Remote Sensing, Wuhan University, 129 Luoyu Road, 430079, Wuhan, China
[b] State-Province Joint Engineering Laboratory of Spatial Information Technology for High-Speed Railway Safety, Southwest Jiaotong University, The Western Park of the Hi-Tech Industrial Development Zone, 611756, Chengdu, China
[c] Faculty of Geosciences and Environmental Engineering, Southwest Jiaotong University, The Western Park of the Hi-Tech Industrial Development Zone, 611756, Chengdu, China
[d] Collaborative Innovation Centre for Geospatial Technology, Wuhan University, 129 Luoyu Road, 430079, Wuhan, China
[e] National Disaster Reduction Centre of China, Ministry of Civil Affairs, 6 Guangbai East Road, 100124, Beijing, China

ARTICLE INFO

Article history:
Received 5 August 2016
Received in revised form
8 December 2016
Accepted 3 January 2017

Keywords:
Flood disaster
Integrated information system
Link
Autonomous activity
3D visualization

ABSTRACT

The flood disaster management system (FDMS) is a platform developed to provide ongoing disaster reduction capabilities that cover the entire process of flood management. The ontology-based approach links environmental models with disaster-related data to support FDMS-constructed workflows with suitable models and recommend appropriate datasets as model input automatically. This automated activity for model selection and data binding reduces the time-consuming and unreliable operations involved in traditional management techniques, which rely on manual retrieval through simple metadata indices—typically when flood management personnel are overwhelmed with large quantities of observed data. The OpenMI-based modular design used in the system unifies interfaces and data exchange to provide flexible and extensible architecture. Subsequent 3D visualization improves the interpretability of disaster data and the effectiveness of decision-making processes. This paper presents an overview of the design and capabilities of FDMS that provides one-stop management for flood disasters.

Software availability

Software name: FDMS (flood disaster management system)
Developer: Wuhan University
Contact address: No. 129 Luoyu Road, Wuchang District, Wuhan City, China. 430079
Telephone: +86 027-68778779
Fax: +86 027-68778229
Contact email: qiu_linyao@163.com
Year first available: 2013
Hardware required: Standard PC
Program language: C++/C# (for desktop client); JavaScript/HTML 5/CSS (for browsers)
Software required: Microsoft Visual C++ 2008/2010 Redistributable Package (x86)
Availability: Customised for the Disaster Reduction Centre of China (NDRCC) and not for free
Trial version link: https://www.dropbox.com/sh/460mh37xisyawj6/AAB6seUDxnNVtvu5F3WF48Hea?dl=0 (software unzip password: w73ujehjx7; data unzip password: 28djng8bl2)

1. Introduction

Flooding is one of the most dangerous and most widely distributed natural disasters in highly developed and/or densely populated regions globally (Guo et al., 2014; Wan et al., 2014). A warming climate may lead to even more frequent and intense flooding in many areas worldwide (Hirabayashi et al., 2013;

Abbreviations: DEM, Digital Elevation Model; EIS, Environmental Information System; FDMS, Flood Disaster Management System; NDWI, Normal Differential Water Index; NDRCC, National Disaster Reduction Centre of China; OWL, Web Ontology Language; RDF, Resource Description Framework; WFS, Web Feature Service; WMS, Web Map Service.

* Corresponding author. State Key Laboratory of Information Engineering in Surveying Mapping and Remote Sensing, Wuhan University, 129 Luoyu Road, 430079, Wuhan, China.
E-mail address: duzhiqiang@whu.edu.cn (Z. Du).

http://dx.doi.org/10.1016/j.envsoft.2017.01.025
1364-8152/

Schmocker-Fackel and Naef, 2010; Solomon et al., 2007). This increased flooding risk is especially alarming for the south central area of China, which has suffered frequently from flood disasters in previous decades (Lu et al., 2016; Zou et al., 2012). Recent developments in information and earth observation technologies provide opportunities to enhance the management, analysis, modelling and visualization of disaster-related data in an information system dedicated to flood disaster reduction.

Environmental Information Systems (EISs) play essential roles in flood disaster management. EISs are becoming increasingly important in tackling grand scientific challenges in disaster monitoring, prediction and assessment by providing integrated multidisciplinary platforms (Granell et al., 2013; Nativi et al., 2013). A critical application domain for these real-time information management systems is flood risk management (Demir and Krajewski, 2013). Large-scale rapid access to earth observation data provides opportunities to improve the timeliness of flood warnings and improve flood preparation and response measures.

However, the exceptionally fast growth in the size and variety of disaster-related data, especially real-time observations, poses a significant challenge to FDMSs. Vast amounts of hydrological and meteorological data are collected daily by a wide range of sensors and instruments (Demir and Krajewski, 2013). With the rapid development of sensor networks and earth observation technology, new satellite, airborne and ground-based remote sensing systems that produce imagery characterised by high spatial, temporal and radiometric resolution have been widely applied. An increasing number of sensors and applications have transformed tablets, smartphones and GPS devices into crowdsourced observation systems capable of delivering an enormous amount of information (Nativi et al., 2015). This enormous change in available disaster-related data requires innovative enabling technologies to improve the integration, retrieval, analysis and presentation of large amounts of information (Grolinger et al., 2013; Nativi et al., 2015) in the flood management field.

This paper introduces the design and implementation of a flood disaster management system (FDMS) that integrates various environmental models and accesses a variety of data sources to provide flood reduction capabilities throughout the entire disaster management cycle. Aiming to allow FDMS to well integrate environmental models and heterogeneous data, this paper proposes an ontology-based approach that links environmental models and disaster-related data through semantics. This approach enhances the flexibility of constructing workflows and takes the initiative in searching data to bind to models in the system. In addition, 3D visualization in virtual global views presents multi-source data more clearly, and the system's modular structure design supports quick functional extensions for new flood reduction demands. This system largely improves the efficiency of flood disaster reduction by reducing time of workflow construction and disaster-related data retrieval, as well as simplifying the man-machine interaction operations of responders.

The remainder of this article is organised as follows. Section 2 reviews related works that present current typical FDMSs. Section 3 describes the linking approach that correlates models and data. Section 4 presents the system design, while its implementation is introduced in Section 5. Section 6 discusses the advantages of the system. Conclusions and future work are provided in Section 7.

2. Related works

Many EISs have already been widely applied in flood disaster management worldwide. Recent examples of these systems have capabilities that apply to different phases of flood disaster management. These systems can be classified into three types according to their functional roles: 1) Some systems integrate atmospheric and hydrological models to implement forecasting, early warning and simulation of flooding in the early stage of flood disaster management (Artinyan et al., 2016; Fotopoulos et al., 2010; Kauffeldt et al., 2016; Wu et al., 2014a). For instance, Delft-FEWS (Delft Flood Early Warning System) is an operational forecasting system that loosely couples many environmental models to provide widely flood forecasting in Europe (Weerts et al., 2010; Werner et al., 2013); the National Flood Forecasting System (NFFS) integrates the grid-to-grid (G2G) model to generate flow forecasts across the United Kingdom (Price et al., 2012); the European Commission launched development of a pan-European Flood Awareness System (EFAS, Bartholmes et al., 2009); the Global Flood Monitoring System (Wu et al., 2014b) adopts the Variable Infiltration Capacity (VIC) model that uses real-time satellite-based precipitation data to monitor floods; H-TESSEL is used in combination with LISFLOOD in the Global Flood Awareness System (Glo-FAS, Alfieri et al., 2013) for flood prediction; and an integrated statistical and data-driven (ISD) framework takes advantage of a series of probabilistic methods to project flood risks (Lu et al., 2016); 3Di, which is based on sub-grid and quad-tree techniques provides flooding simulation for planning analysis and real-time forecasting applications in flood disaster reduction (Dahm et al., 2014). 2) Some other flood information systems focus on information extraction and assessment in emergency response and recovery after a flood disaster occurs. For example, the NAZCA WebGIS 3D application provides flood risk assessment and damage evaluation functions based on feature extraction from remote sensing images (Serpico et al., 2012); the Iowa Flood Information System (IFIS) provides access to flood inundation maps, real-time rain runoff conditions, flood-related data and interactive visualizations for planning responses (Demir and Krajewski, 2013); and a decision-support system (DSS) based on flood data and mitigation or recovery options was developed for both naïve and expert users to evaluate portfolios of flood mitigation or recovery measures (Zagonari and Rossi, 2013). 3) Still other information systems manage and share information concerning disaster cases. For instance, the Environmental Virtual Observatory pilot (EVOp, Vitolo et al., 2015) presents statistical evaluations of flood information using web maps, and CyberFlood (Wan et al., 2014) manages several global flood databases and supports reporting new flood events using a crowdsourced data collection methodology. The system classification is listed in Table 1. Most systems statically integrate one or several models to provide flood reduction functions to meet the requirements of one or two phases of disaster management.

It is essential for responders to continuously monitor the status of developing disasters to make efficient responses during the entire process of disaster management. The four phases of disaster management (mitigation, preparedness, response and recovery) (FEMA, 2001; Köhler and Wächter, 2006) are ongoing and not independent (Pu and Kitsuregawa, 2013). These characteristics are prominent in flood management because flooding is a continuous, complex and changeable process, and there are no clear boundaries between adjacent phases. Current disaster management systems mostly play a role in one or two phases of disaster management, but are not used over the entire disaster management process. Instead, each system develops functions and integrates models that are oriented to the requirements of disaster reduction in certain phases. Therefore, responders are forced to operate more than two systems during the processes of continuous disaster monitoring, emergency response, damage assessment and the other flood reduction tasks that span the full management period. However, flood disaster management that requires multiple systems may reduce efficiency and can be time-consuming: the obstacles lie in workflow construction and data integration that must consider