Web-based Data Monitoring, Analysis, Reporting and Management for Field Measurements

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Abstract This paper describes the concept, implementation and application of the Web based hydroinformatics system ‘Turtle’ for data monitoring, analysis, reporting and management in field measurement programs. The system uses a generalised object-oriented approach for information modelling by tensor classes and is implemented platform-independently as a Web application. This leads to a more flexible handling of measurement information during and after measurement programs in a distributed and interdisciplinary environment. The potential and advantages of Web-based information systems like ‘Turtle’ are described for a measurement program dealing with the physical limnology of Lake Constance/Europe 2001.

Keywords Web-based Hydroinformatics Systems, Information Modelling, Data Management

1. Introduction

Hydroinformatics deals with two important ‘raw materials’ of the human society: water and information. Both are basic resources of hydro-engineering projects to adapt the natural environment by artificial infrastructure to satisfy the demands of the human society. Planning, design and control of artificial infrastructure is based on a deep understanding of the natural environment such as physical, chemical and biological behaviour and the interaction with human interventions. This demands huge efforts on field observation and physical experiments as well as on computer-based simulations. However field measurement data from corresponding measurement programs are not replaceable. Modern measurement techniques allow suitable accuracy and density of data recording but also require a careful preparation, performance, analysis and archiving of the field experiment. The results are mass data with respect to the different spatial and time dimensions. On-line monitoring and pre-analysis during the program ensure the quality of the measurements. Post-analysis, detailed reporting and long-term archiving lead to a (hopefully beneficial) scientific and practical use of the measurement information in balance to the measurement efforts. All these demanding tasks and the mass data management require the application of a corresponding suitable information system.

Measurement programs and hydro-engineering projects are performed by heterogeneous teams of experts from different disciplines, working at different locations. Modern Internet/Web technologies allow the set up of Web-based information systems to support a platform-independent distributed collaborative engineering. This kind of information system is changing the way of collaboration from ‘information exchange’ to ‘information sharing’ - a new challenge for modern engineering in the time of the ‘Internet Revolution’ and ‘Globalisation’. This paper describes the Web-based information system ‘Turtle’ designed and applied to a measurement program dealing with physical limnology of Lake Constance/Europe during October/November 2001.
2. Measurement Program Lake Constance 2001

2.1 Target and Partners
Lake Constance as one of the largest lakes in Central Europe has great importance as a unique ecosystem, drinking water storage and as a basis for professional fisheries. The understanding of the movement of the water and the numerical modelling of its hydrodynamics are important steps towards a sound basis for future decisions of lake managers in order to ensure high water quality. The joint research project "Modelling of High-Frequency Internal Waves in Lakes" of the Institute of Hydraulic Engineering (IWS) at the University of Stuttgart and the Centre for Water Research (CWR) at the University of Western Australia, partly funded by the DFG (German Research Foundation), deals with the modelling of groups of short-period internal waves in stratified lakes. A field measurement program in Lake Constance was part of this project and the measured data serve as a basis for the validation of the existing simulation program CWR-ELCOM (Estuary and Lake Computer Model) as well as for a better understanding of the generation of high-frequency waves in Lake Constance. In addition to the IWS/CWR measurement program, other research institutions conducted measurements of currents during the same time period.

2.2 Measurement Concept and Data
Between 11 October and 17 November 2001 intensive measurements were carried out in Lake Constance. The objective was to measure the spatial and temporal wind field over the water surface (wind speed and direction) and the internal wave response of the lake from basin-scale internal waves down to high-frequency waves. Therefore eight CWR Lake Diagnostic Systems (LDS) were installed at fixed locations in Lake Constance and one station was installed at the shore, which communicated via GSM telemetry.

The lake stations measured water temperatures at 50 points over a depth of 100 m and wind speed and direction in 2.4 m height above the water surface. One lake station was additionally equipped with a weather station, measuring relative humidity, air temperature, incident short wave radiation and net radiation. All sensors of the lake stations were generally sampling in 10 sec intervals in order to measure high-frequency internal waves. The lake stations were controlled by the already existing CWR LAKEMON software at the shore based station, where the data were collected at regular intervals of 1 hour or 4 hours via GSM mobile phone telemetry. The raw and converted data files were stored locally and after collecting 1 MB of data, sent to the CWR Field Operations Group in Australia, where the data were automatically visualised with Matlab scripts and directly posted on a Web page (see references). In addition to the existing CWR LAKEMON system, a new Web-based information system 'Turtle' was applied to get experience on the potential of modern Web technology and information modelling concepts for such measurement programs.
3. Measurement Information Modelling

Measurement data differ much in type, dimension and structure. Conventional information systems are specialised for the specific measurement techniques, sometimes using standard data bases. Usually they do not combine data with functions and explicit semantic towards independent information units. Specific export filters and interfaces to analysis, visualisation and documentation packages ensure data exchange to other tools. This leads to specialised software packages not designed for a platform-independent and net-based application in a heterogeneous environment.

Measurement data are usually used for scientific analysis or operational improvements by several experts from different institutions and disciplines in a heterogeneous computer environment. The applied analysis methods and related software tools differ in their internal data formats and in the support of external interfacing - an obstacle for trans-institutional and interdisciplinary collaboration. Most users do not have the time to develop and apply standardised formats or interfaces. This leads to several incompatible 'personal' versions of the 'valuable' data with high amount of implicit information. Information exchange/sharing is restricted. In the long-term - based on the staff exchange - there is a loss of data, knowledge and experience. Application-independent information systems for measurement monitoring, for long-term data analysis, reporting and management as well as for interdisciplinary collaboration are rare.

Modern information and communication technology (such as OOM, XML, Web technology, distributed data bases) in combination with well-known engineering basics from mathematics (such as set and tensor theory) enable the introduction and application of flexible and platform-independent information systems as standard tools. They might reduce the implementation effort and increase the flexibility for net-based collaboration in heterogeneous, interdisciplinary and distributed environments. Prerequisite is a generalised information modelling approach for the relevant measurement data in combination with the corresponding semantic and functional/operational properties.

Tensor-based Information Modelling for Physical State Variables

The basic idea for information modelling of measurement data is the application of object-oriented modelling (OOM) by generalised tensor class families. Objects and the corresponding classes describe semantic information units by attributes (data), methods/behaviour (internal functions) and operations (external interfaces). The application of object-oriented principles allow to set up a powerful system-independent class family for component-oriented system development. This kind of information modelling can be easily applied to hydroinformatics for physical state variables such as data from measurement programs and software simulations.

As an example, physical state and behaviour variables for one- and two-dimensional water-related physical processes can be structured by the dimension of the corresponding coordinate systems as scalars (coordinate independent variable), functions (variable depending on one coordinate) and fields (variable depending on two coordinates). More types of variables depending on three or more coordinates can be easily extended but will be not considered in this paper. The number and order of values is a second property to classify physical variables as units (one value), sets (several independent values) and vectors (sequential ordered values). These two classifications lead to nine tensor classes covering all typical kinds of data for one- and two-dimensional measurement and simulation models in hydroinformatics systems. Details of this concept is described in Molkenthin (2000).
Measurement data can be easily described by these system-independent tensor classes with all attributes, methods such as numerical analysis (integration, differentiation, mean value) and related standard tools for user interfaces (forms, diagrams, tables and reports) as Web objects. The tensor classes and corresponding tensor tools form the core components of Web-based information systems for field measurements. The set up of such a system is reduced to the modelling of the relevant measurement data by tensor classes and the composition of the information system by standardised tensor tools and some few project specific tools. This approach of tensor-based information modelling in combination with the application of modern Web-Technology has been used to develop the measurement information system ‘Turtle’ for the measurement program ‘Lake Constance 2001’.

4. Web-based Information System Turtle

4.1 Turtle Information Model

‘Turtle’ was developed as the Web-based information system to handle all data of the field measurement program during October/November 2001 in Lake Constance/Europe. All field measurement data (see chapter 2.2) were modelled by the described tensor classes: the water temperature $T(\text{depth}, \text{time})$ as a scalar field, the wind speed and direction $v, \alpha(\text{time})$ as a function set and air temperature, humidity, short wave radiation and net radiation as a function unit for each of this variables. These tensors form a tensor set for each of the eight measurement stations in the lake. All tensors were filled with the measurement data by reading the different ASCII measurement files generated by the CWR LAKEMON software.

4.2 Implementation

The system has been implemented as a platform-independent and net-based software product using Java-technology. The implementation effort was reduced significantly by reusing generalised Java class packages for tensors and user interface instruments. Most effort has been spent for the classes to read the different data formats as tensors and the interfaces to generate HTML report pages for the specific measurement program. The system supports different applications modes like stand-alone application, thin client mode (DHTML/Servlet) and fat client mode (Applet/Servlet) to support the application via Internet in distributed project environments.

4.3 Application

The system was applied during the measurement program for the pre-analysis and afterwards for reporting the whole data set. The involved experts used different hardware components (notebook, desktop computer and server) with different operation systems (Linux, Windows 98, Windows 2000) and different Web tools (Netscape, IE 5.0). The whole system was installed on these heterogeneous environments without any adaptation to the specific platform. This underlines the advantage of platform independence by Java-technology. The system will be reported in the Web [http://www.iws.uni-stuttgart.de/~hfwave](http://www.iws.uni-stuttgart.de/~hfwave). The system has been applied for three important project steps: on-line monitoring during the experiment, pre-analysis and information mining as input for simulation models afterwards as well as long-term reporting and archiving of the measurement results for later reuse. The functionality of ‘Turtle’ for these three application steps will be briefly described.
Application during the Measurement Program

The main application of ‘Turtle’ during the measurement program was the on-line check of the data in order to detect technical problems and to get a first pre-analysis in respect to the physical behaviour of Lake Constance. The transmitted data files were automatically checked by ‘Turtle’ for gaps, transmission errors, calibration errors and plausibility. HTML report pages were generated including key information (e.g. mean values), visualisation (function plots, isotherm plots) as well as the whole data set. In this specific experiment the reports were stored on local systems for final testing. However, ‘Turtle’ allows to generate these reports directly on a Web server. All involved experts would than have had always open or password-protected access to these on-line reports to observe the ongoing field measurement and to have an updated overview on the actual situation in the lake independent of their location. All necessary analysis and visualisation functionality for this service were applied by the tensor class methods without any special implementation effort.

Pre-Analysis

The pre-analysis functionality of ‘Turtle’ was used during and shortly after the measurement program. Main feature for this purpose is the gridding functionality to convert the originally measured tensor objects on different time interval scales interpolating gaps and decreasing the data density by mean values. Besides the 10 sec time step this feature was used for 600 sec (10 min), 3600 sec (1 hour) and 86400 sec (1 day). This additionally generated tensor set allowed a flexible zooming between the different time scales to detect high-frequency and long-frequency behaviour of the lake. Corresponding Web objects (diagrams and generated DHTML pages) provided suitable user interface instruments for this important feature. Export interfaces (e.g. Matlab format) allowed to process the pre-analysed data on the chosen time scale in other tools such as numerical simulation systems.

Reporting and Archiving

The performed measurement programs led to a huge number of valuable data and corresponding information. A detailed reporting and complete archiving ensured the long-term access to the obtained information. Traditionally, this has been done by printed reports and ASCII data files in software-depending formats. ‘Turtle’ supports this important task by a new concept. The whole measurement data set was reported by generated HTML pages, including data tables, generated images for visualisation and interactive features (JavaScript, Applets) for navigation and zooming in the measurement data space (station, time, time step size and water depth). Additionally all tensor objects were persistently stored in a self-describing XML format. We hope, this way of platform- and tool-independent reporting and archiving will enable the reuse of the measurement program results in the long-term. However, published on CD/DVD or offered for downloading via the Internet the data can be used by partners from different disciplines with their different tools just now – an important step to support interdisciplinary and international collaboration in the Internet.
Conclusion

Web-based hydroinformatics systems based on modern information modelling methods and platform-independent Web technology open a new level to support interdisciplinary and distributed collaboration in hydro-engineering. Field measurement programs require such a support for flexible information handling during and after a measurement program. The application of the Web-based information system ‘Turtle’ for the measurement program ‘Lake Constance 2001’ confirms the potential of this approach. ‘Turtle’ offered an even more flexible tool to access and handle the measured data quickly with a tremendous effort (time) reduction for the involved experts. Of course, this approach can not produce explicit new physical insight – the measurement data and the scientific analysis methods are still the same as in comparable measurement programs before. However, the application of this generalised approach provides amongst other important features:

- fast information access during the measurement for on-line pre-analysis world-wide
- different interdisciplinary views on the same data set
- integration of different data sources on the same level as tensors
- support of distributed collaboration by information sharing instead of exchange
- flexible information ‘zooming’ on different time windows and time step scales

The generalised information modelling approach offers experts besides their conventional tools and methods a more generalised view on the data and the opportunity to apply analysis methods from other disciplines. This is an important step for interdisciplinary collaboration. By reducing the effort/time for information handling and by increasing the flexibility for different information views such systems allow the involved experts to spend more time on their original task: the physical insight of the aquatic environment for engineering purpose.

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