Wireless Remote Animal Monitoring (WRAM) – A new international database infrastructure for telemetry sensor data from fish and wildlife

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Abstract
During the recent years new tracking and sensor technologies have become available to ecologists and natural resource managers. New sensors are integrated into tracking units on animals in a fast pace and data transmission in near-real time has become the norm rather than state of the art. A crucial limitation today is the lacking of e-infrastructure to collect, store, and visualize these data in an automated fashion. The Wireless Remote Animal Monitoring (WRAM) system was developed to automatically capture, store, and visualize primarily GPS data. It is built in modules around a central relational database system. Currently the system hosts data for 1,649 animals from 12 species in 4 countries, resulting in 72.8 million database records (April 2012). The WRAM e-infrastructure is currently being upgraded by grants from the Swedish Research Council to become the national data node and data sharing portal for real-time telemetry sensor data from fish and wildlife as part of the Swedish contribution to the European LifeWatch initiative to enable data sharing of sensor data across projects or national borders. WRAM is currently cooperating with several other national or international database initiatives such as MoveBank (Germany), EuroDeer (Italy) or CanMove (Sweden) to provide the means for several on-going or planned joint wildlife research projects across Europe. Here, we give an overview of the different parts of the e-infrastructure, including automated data capture tools, database schemes, data sharing approaches, and web-based visualization tools.

Key words:
Telemetry, wildlife, fish, sensor, GPS, database, biologging, GIS

Introduction
During the recent years new tracking and telemetry technologies have become available to ecologists, researchers and natural resource managers, allowing remote data capture from a steadily increasing number of taxa, species and individual animals. GPS-units for terrestrial and avian species are constantly improving in performance and durability, while simultaneously becoming more affordable. New sensors monitoring health status, individual interactions or other environmental variables are integrated in to these units on animals in a fast pace, and data transmission in near-real time...
using cell phone or satellite networks has become the norm rather than being considered 'state of the art'. This has resulted in a substantial increase in data volume gathered by research, environmental monitoring and public agencies. A crucial limitation for efficient use of this technology is that in many cases basic research still lacks the e-infrastructure to automatically collect, store, and visualize these data, in order to utilize its full potential. While data management, storage and visualization is addressed recently by several authors (e.g., Cagnacci & Urbano 2007; Hartog et al. 2009; Urbano et al. 2010; Kranstauber et al. 2011), automatic data capture remains a major challenge for many researchers (Coyne & Godley 2005).

The Wireless Remote Animal Monitoring (WRAM) system deals with many of these problems in an automated fashion, minimizing the time needed for a user to supervise data capture and storage, once the units are deployed on an animal. The software was originally developed to automatically capture, store, and visualize GPS data from moose in Northern Sweden in near-real time using GPS/GSM-collars from one single provider (Dettki, Ericsson, & Edénius 2004). Currently the system hosts location, acceleration, and temperature data for 1,649 animals from 12 species in 4 countries, resulting in 72.8 million database records (April 2012). WRAM handles at the moment 10 data formats from 6 different sensor providers. The WRAM e-infrastructure is currently be upgraded by grants from the Swedish Research Council. It is tasked to become the national data node and data sharing portal for real-time telemetry sensor data from fish and wildlife as part of the Swedish contribution to the European LifeWatch initiative to enable data sharing of sensor data across projects or national borders. WRAM is currently cooperating with several other national or international database initiatives as MoveBank (Germany), EuroDeer (Italy) or CanMove (Sweden) to provide the means for several on-going or planned joint wildlife research projects across Europe. Here, we give an overview over the different parts of the e-infrastructure, including automated data capture tools, database schemes, data sharing approaches, and web-based visualization tools.

The WRAM 1 software platform and features

WRAM is a software platform to automatically capture, store, and visualize sensor data from animals. It contains as the central part a relational database management system (RDBMS; MS SQL Server 2008 R2 or MS SQL Server 2008 R2 Express). Data capture into the database is handled by programs ‘SQLInsert’ and ‘ReadMail’ (VB.NET), in combination with sensor-provider proprietary software as VAS GPS Plus, VAS GP Export (Both Vectronic Aerospace GmbH), and MTI GPS Parser (Microwave Telemetry, Inc.). Data visualization is done in a web browser using ArcIMS 9.3.1 (ESRI 2004) with a customized HTML Viewer (ESRI 2004). Further, coordinates of the latest position of each animal can be accessed by a cell phone using the ‘Short Messaging Service’ (SMS) with the program ‘SMSQuery’. All scripts and source code developed by the authors are licensed with the BSD-license (OSI, 2008) and can be requested from the authors.

WRAM 1 database

In the database, all data is stored for each sensor in a different table, with each individual record in a tabular format. Information about the individual animal, sensor IDs, and time frames of sensor deployment on this animal is updated by the user through a Microsoft Access frontend connecting to the database through the Open DataBase Connectivity (ODBC) protocol. This information is always correlated with the sensor data to ensure that only relevant data, i.e., data collected by a sensor on a specific animal, is shown to the user. Additional data, as e.g., information on sun rise and sun set for each recorded location is generated automatically on a daily basis.
The access to the data is restricted, either on a project basis, giving the user access to all individuals and associated datasets within a project, or on an animal level, where only single or groups of individuals and associated datasets are shown to the user for which they have authorization.

The users can access the datasets, predefined reports and views through the ODBC protocol, using client software as e.g., MS Access frontend or any other analysis software, statistical package, or Geographic Information System (GIS) which supports the standard ODBC protocol. Hence, the system gives the user the full flexibility to use the most appropriate analysis tool for the scientific task at hand and is not limiting the user to a set of predefined, build-in analysis tools.

**Remote Data Collection**

WRAM automates the process of retrieving and parsing data from different sensors and providers into the database as far as possible, enabling users to concentrate on analysis and interpretation of the data instead of data management. Where manual data upload is necessary, e.g., when data must be downloaded manually from the sensor or in case of archived data collected before the user joined the WRAM platform, the user simply emails the data file in the original proprietary format to a functional email address. It also enables users to set up their own automatic receiving stations and send off the received data files to the central WRAM database. This is particularly important when using the GSM system or equivalent cell phone network for data transfer. Sending data-SMS between different cell phone network providers or countries can increase the data transfer costs many times due to network roaming. It is often cheaper to set up a receiving station (GSM-modem) in the same country where the animal is located rather than let the sensor send its data across national borders.

The way data can be collected by the system depends on the proprietary infrastructure of the sensor provider. While some providers allow the users to set up their own receiving stations to receive data-SMS through a local GSM-modem using their proprietary software to decode and export the data to a text file, other providers use a company-owned receiving system. They are then simply sending emails with the data in the email-body or as attachment to the user. The WRAM system can handle sensor data sent by Argos, Iridium, or GSM in a uniform way (Fig. 1): The data is received as SMS or email by proprietary software of the sensor provider or as email by the WRAM program ‘ReadMail’, if necessary parsed into a readable format, and exported into a standardized text file. These text files are then read by ‘SQLInsert’ and inserted record-wise into the database. A simple quality tag is applied on insertion, allowing the user to filter out dubious sensor readings. The user can also send an email with any manually retrieved data from the sensors to the program ‘ReadMail’. The system is working with both Vectronic Aerospace GmbH (VAS) and Lotek, Inc. hardware (GPS/GSM-units & GPS/Iridium-units) and software (GPS Plus), Televilt AB (TGV) GPSDirect and Tellus GPS/GSM-units, FollowIT AB (FIT) GPS/GSM-Tellus and Tellus Domestic GPS/GSM-collars, and Microwave Telemetry, Inc. (MTI) GPS/Argos-units and software (GPS Parser). Data retrieved manually from the units through a VHF or UHF-link or by cable-download can be sent into the database by email for VAS, Lotek, and Telemetry Solutions, Inc. GPS-units.

**Visualization**

A web application, based on HTML Viewer (ESRI 2004) and enhanced with Active Server Page technology (ASP) and Visual Basic, both in the Dot Net framework (Richter 2002) on an Internet Information server 6.0 (IIS 6.0, Microsoft Cooperation 2005), enables the user to visualize either the latest positions for all animals or the movement path of a single animal for a project specific interval backwards in time from now on top of the back ground map. The movement path is color-coded to show movement before and after sunset in different colors. Additional information is given in
tabular form on collar properties as e.g., VHF frequencies or animal properties as e.g., age or weight. Further, position co-ordinates or simple statistics as e.g., movement path length or number of received positions are shown as HTML tables. Digital topographical maps (original scale 1:100,000) obtained from Swedish, Norwegian, and Finnish land survey agencies are used as background maps. They are published as ArcIMS 9.3.1 Image services (ESRI 2004), which in turn are consumed by the HTML Viewer.

Fig. 1.: WRAM data flow: Data from different providers and through different transmission methods is automatically handled, decrypted, and parsed in the staging area, to be inserted into the database server. It can be accessed through ODBC clients or cell phones; and is visualized on an interactive web map.

Access to the website is restricted to authenticated users only, showing some or all animals depending on the authorization of the user. Some projects decided to make their data publically available on a public version of the web site, requiring no authentication. Usually the public web sites omit the access to some attributes as e.g. co-ordinates and only show data which are at least a few weeks old to protect the animals. In some cases, as for wolves, were information on the exact location is very sensitive, the exact spatial positions are omitted at all and only a 10x10km square is shown which contains the latest position of the animal, in order to prohibit non-authorized use of the exact position (http://webmap.slu.se/website/vargwebb/).

The latest position of an animal together with additional information as e.g., date and time of the position, height, VHF beacon frequency and Dilution of precision (DOP) can also be obtained by sending a specific SMS to the local GSM-modem. After reception through the GSM-modem, the message is stored as text file on the server the GSM-modem is connected to. The program ‘SMSQuery’ reads the incoming text files containing parameters for the senders’ phone number (Caller-ID), database access and animal ID, queries the database with these parameters, and send a position-
SMS (text-SMS with co-ordinates) back to the user. Access control to the database is managed by checking the senders’ phone-number against a list of authorized cell phone numbers for the specific projects.

The new WRAM 2 e-infrastructure

The proven WRAM 1 platform is currently being upgraded by grants from the Swedish Research Council to become the national data node and data sharing portal for real-time telemetry sensor data from fish and wildlife as part of the Swedish contribution to the European LifeWatch initiative to enable data sharing of sensor data across projects or national borders. The infrastructure is expected to be fully operational in mid-2014.

Fig. 2: WRAM 2 e-infrastructure (WDW & WDB): The WRAM Data Warehouse accepts data and meta data from different sources and links up with other local databases in the WRAM Data Broker. Here, a portal & temporary database are hosting results from user queries, aggregated data is submitted to other, high level data nodes, and user access is managed.

The WRAM 2 e-infrastructure consists of two major parts (Fig. 2), the WRAM Data Warehouse (WDW) and the WRAM Data Broker (WDB). The WDW will improve performance of the existing storage system and enable the easy integration of new and future sensor types without the need of structural change within the data storage. The WDB will enable the user to query not only data stored in the WDW, but also data in partnering fish- and wildlife sensor initiatives. Therefore data provided by Movebank (Kranstauber et al. 2011), EuroDeer (2011), or CANMove (2012) can be accessed in one single framework, given the proper authentication of the user and authorization for these datasets. Further, metadata on all datasets will be made available in an automatic fashion in the Swedish part of the European LifeWatch initiative (Swedish LifeWatch 2011), and through this cooperation even in the GBIF (Global Biodiversity Information Facility 2012) and ECDS (Environment Climate Data Sweden 2012) metadata repositories. This will make
it possible for researchers to share their sensor data from fish and wildlife in a controlled fashion in a common, modern e-infrastructure and make it searchable for the wider scientific community.

![Diagram](image)

**Fig.: 3.** WRAM Data Warehouse schematics: The Real Time ETL handles data collection and quality control in a staging area and distributes the data, depending on the age of the measurement, to the Real Time or Historic Data Warehouse. A Daily ETL moves older data from the Real Time to the Historic Data Warehouse and checks data quality.

**WRAM Data Warehouse**

The WRAM Data Warehouse (WDW; Fig. 3) features a staging area to process the received data before making it available in the Warehouse. The data is then available either in the Real Time Data Warehouse (Real Time DW) or the Historic Data Warehouse (Historic DW). Two ‘Extract, Transform and Load’ (ETL) processes are used to process the data. The ‘Real Time ETL’ process runs every 5 minutes, loading new data into the Real Time or Historic DW as required. A ‘Daily ETL’ process moves data from the Real Time DW and into the Historic DW when it is 4 weeks old. Meta, Summary and the raw data is available within each DW as well as several Data Marts, i.e., views which can be customized for different user requirements. The benefits of the design are that as the amount of new data being received increases, the effect on performance for most of the end user activities (as e.g., querying of Historic and Real Time Data Warehouses) is minimized by utilizing a Real Time DW and staging area to load from.

To enforce data quality, two Quality Control and Correction (QC+C) processes are utilized. The Real Time QC+C process runs only rules that do not require excessive processing time. The Daily QC+C process, however, runs the rest of the rules on recently received records in both data warehouses. All QC+C rules and results are recorded as metadata so that users can trace the data quality of the individual data records. Additional QC+C rules can be added very easily without core changes to the system design.
Both the Real Time and Historic Data Warehouse follow a Normalized Data Store design. Measurement data from all sensors is stored in a single generic serialized table (Fig. 4). This is a major change compared to the ‘1 sensor type – 1 table’ structure of the old WRAM 1 system. By this, the WDW can cope with future sensor types which will send measurement data which cannot be specified at this time. As new sensors come online, measuring new types of measurements or using new units, this data can be captured in to the existing generic table without the need to change the basic structure of the WDW.

Fig. 4.: Normalised database schema for WRAM 2 with the generic serial table design (Table MeasurementsSerial), indicating the relations Animal – Tag – Sensor – Measurement.

From this core data structure, metadata is generated (e.g., accuracy of data acquisition) and the results of the data quality assessment are added. The system also produces a star scheme based on Fact and Dimension tables, thus allowing users to choose which version to use to best suit their analysis.

WRAM Data Broker

The main goal of the WRAM Data Broker (WDB) is to federate a number of different data warehouses with similar sensor data from animals (as e.g., WDW, Movebank, or EuroDeer) without the need of a permanent centralized data store. After identification through an authentication procedure a user will be able to access data from one or more data warehouses, either through a dynamic web portal or directly through an ODBC link to a temporary frontend database table (Fig. 5).
After the user acquires an OpenID token from a 3rd party identity provider, this is sent via HTTP headers to the portal service. From here, data in each data warehouse is accessed through a web service, after the OpenID token is translated into local user accounts to restrict the access to the user’s local permissions. The web service features a translation layer to normalize the different database schemes of the different data warehouses. The results of the query are then presented back to the user either as a HTML table on a dynamic web page or as a temporary database table secured by a temporary user name and password.

The WDB is also used to automatically consume and aggregate data on a regular basis available from the connected data warehouses. This information is made available to the Swedish LifeWatch database. By this, information on the existing datasets available through the WDB to eligible users becomes searchable for the wider scientific community. This will simplify cooperation between projects and research across national borders.

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