xS+S
**x Software + Systeme*

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IT Concepts for Online Water Quality Monitoring Networks

Tasks, Requirements and Realization Possibilities of modern Online Monitoring Technology

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Summary: Online Environmental Monitoring Networks can be successfully established where simultaneous, continuous and near real-time measurement of many physical parameters on many different sampling locations is required. Set up and maintenance of such a monitoring network is not a trivial task at all, as the seamless cooperation of many different technical subsystems is required. This paper tries to give an overview of the requirements, tasks and possible solutions to implement an online monitoring network from the perspective and experience of several successful real-world applications.

Key-Words: Water quality, Measurement data, Online Monitoring, Quality Assurance, Database, Presentation, Telemetry

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1. Online Monitoring Technology

Measurement as method of gathering the characteristics of a real physical condition is an important step to calibrate a model of a system which was designed to provide means for planning, analysing, assessment or prognosis of a real-world situation.

Models in the meteorology, air- and water quality, water treatment, water supply and water disposal domain more than often comprise geographically large areas, a huge number of different physical parameters and require processing of data over a long time frame of several months or years.

To produce high-quality input and reference data for these models, a huge number of measurements over a large geographical and temporal area with a high resolution in all dimensions is needed.

Manual sampling, sample preparation and laboratory analysis is expensive and not sufficient for these tasks and even impossible in some applications like with sampling periods as small as one minute in a highly dynamic medium.

In these situations, automatic sampling and measuring on site or even directly in the medium ("in-situ") is necessary. As soon as there is a need to access the data in a near-real-time way, an online monitoring network is the only way to fulfil all these requirements.

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2. Online Monitoring Network Requirements

The main task of an online monitoring network is the automatic and continuous acquisition, recording, processing and presentation of measurement data of several geographically distributed sampling locations in high timeliness and quality.

This short definition lists all essential requirements an online monitoring network has to meet. Depending on the actual application, other functional and non-functional requirements can exist, too, but the primary definition still remains valid in any case.

In the following chapters we will look at each part of this definition in more detail.

2.1 Automatic

An online monitoring network performs its tasks with little user interaction. On-site and in-situ sampling and preprocessing of data is usually done completely without or only with minimal human interaction. Other automatic and autonomous tasks for example can be periodic cleaning and calibration of sensors, preparation of standard data presentations or supervision of system conditions and alert management.

2.2 Continuous

An online monitoring network usually performs its tasks without interruption and around the clock, 24 hours a day, 7 days a week (24x7 operation). If some components of the network break, the network as a whole still has to provide it's functionality to the user.

To reduce the complexity of the system and amount of data in the monitoring network, the time domain usually is divided into units of adequate size, for which a single sampling of the physical parameter is sufficient. This smallest unit of time in the measurement process is called “measurement interval“, the result of the measurement process is called “atomic measurement value“. The adequate size of this time unit depends on the medium as well on the measurement task itself. In a highly dynamic medium or sampling location like a sewer or fast flowing river, the measurement interval has to be much shorter than in a slow medium like a WWTP aeration tank or slow flowing river or lake.

2.3 Data acquisition

One main task of an online monitoring network is the acquisition of data by measuring the physical conditions of the medium. Data acquisition is usually done concurrently in parallel on several geographically distributed places (“sampling location“) and in certain time intervals (“measurement interval“)

Result of the data acquisition task is the atomic measurement value of the requested physical parameter, directly connected attributes like time stamp or sampling location, as well as additional information depending on measurement methods like statistical information, quality assurance information or data about measurement conditions.

It has to be mentioned that, depending on the sensor technology, some sensors for a single measurement interval internally use several single measurements to provide the measurement result. As far as these internal measurement values are not accessible from outside the sensor, the “external“ measurement result is still considered an “atomic measurement

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value“, which can be used in all further processing of the data without restriction, as long as it meets the quality criteria defined by the network.

The task of continuous data acquisition over a period of time provides a “time series“ of atomic measurement values, including additional information, for all monitored physical attributes in the network. Time series can be equidistant (with constant measurement intervals) or non-equidistant (with variable measurement intervals)

2.4 Data recording

All acquired measurement values are usually recorded in a way, so that all values can be unambiguously assigned within their context and efficiently accessed for data presentations later on.

Usually, the following different storage areas are available in an online monitoring network:

- Short-time sensor storage
  To collect intermediate values needed for the measurement, depending on measurement method and implementation.
- Short time monitoring station storage
  Temporary storage for all collected data on the on-site monitoring station over a short period of time (several hours to days). This storage area can be cleared when the data is finally and completely transferred to the central station.
- Short time central station storage
  To provide fast access to measurement data for central station special applications over a short period of time (several days to weeks)
- Long time central station storage
  Direct access storage for measurement values, additional data and meta data for online presentations, reports and all other main tasks of the central station.
- Cache storage for special applications
  Storage buffer for access to data by public presentations (e.g. Internet presentations for anonymous access). This buffer is usually used to separate access and to reduce the load on the main database of the central station.
- Archive (Offline storage)
  Long-time data storage and archive on external media. Direct access is not possible on this storage device and usually needs some additional manual steps to put the data back online.

The size of each storage area defines the amount of data which can be recorded in each measurement subsystem.

2.5 Data processing

All data acquired by measurement sensors has to be processed by means of different algorithms and methods to increase the quality and information content of the data for the user.

Data processing methods can cover the following areas:

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- Plausibility checks
  Different methods of quality assurance and quality control to make sure the database contains only valid or correctly marked data.
- Correction
  Use of different methods and algorithms to compensate for known systematic errors throughout the measurement chain. That way the precision of measurement values can be increased. Automatic correction algorithms can utilize results of sensor calibration to compensate for offset and drift and so minimize the difference between the real physical value and the measurement result.
  To maintain high quality measurement results, a thorough utilization of automatic correction algorithms as well as reference- and calibration-data is necessary.
- Aggregation
  Aggregation is the task of combination of several atomic measurement values to a single "aggregated value" by use of adequate algorithms. The goal is to reduce the amount of data by removing unneeded details and thus increasing the information content in the system by "condensing" the data. A typical aggregation example is the calculation of arithmetic mean values out of several atomic measurement values.
  In an online monitoring network aggregation is usually done in the geographical and temporal domain by means of several different aggregation algorithms. A careful choice of aggregation algorithms as well as consideration of aggregation rules and conditions (validity of data, valid data count, ...) is essential to achieve correct and valid aggregated measurement values.
- Supervision
  Supervision is the task of continuously monitoring data and state in the network by applying predefined supervision criteria. This process generates additional information which then can be used to change the monitoring network state (e.g. reduce the measurement interval in case of pre-alarm situations), activate measurement network control functions (close some valve or start automatic sensor calibration) or initiate an alarm (e.g. in case of some parameter threshold is exceeded).

The above mentioned data processing methods and algorithms can be performed automatically without user interaction, automatically with confirmation by the user or completely controlled by the user of the monitoring network. Each method or algorithm described here can be implemented by different components of the online monitoring network and even need the interaction between several network components.

All data processing methods and algorithms create, in addition to possibly modified measurement data, additional information like markings, flags, log messages or state information, which gets stored into the database to provide additional means for the user to classify and interpret the measurement data.

2.6 Data presentation

One of the main tasks of an online monitoring network is the presentation of acquired and processed data in a suitable way and to provide access to the data to all interested persons and institutions.

The system has to differentiate between several different user groups:

- Technical staff

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- Scientific personnel
- Authorities
- External institutions
- Public

For each user group, different access rights to the data and information stored in the online monitoring network database have to be taken into account. Access rights can be bound to the processing level or quality level of the measurement values, time stamp or sampling location. Suitable authentication and authorisation methods have to be provided.

Access to data has to be provided in several different ways and methods.

Examples for different data access methods are:

- By means of a specialized, machine readable data transport protocol for further processing by other software, possibly located on another computer.
- Presentations, reports, protocols in graphical and tabular form on screen or paper, suitable for human processing and interpretation.
- Prepared for the presentation in a web-browser for easy access to the data through the Internet or intranet.

2.7 Sample location

The sample location is the geographically distinct place where the samples of the medium are taken, or, in case of in-situ monitoring, the sensors are directly put into the medium. An important advantage of an online monitoring network is the possibility to concurrently and continuously acquire data on several sample locations which are located throughout a geographically large area at relatively low costs. Usually, an online monitoring network deploys a large number of sample locations to make the best use of these advantages.

2.8 Timeliness

Availability of near real-time data is another important criteria for an online monitoring network. Even if a large number of sampling locations is in place, by use of suitable communication technology an overall latency (time between the sampling and availability of processed measurement results in the central station) of a few minutes can be achieved. With conventional and manual methods (laboratory analysis) this is just impossible or at least vastly expensive.

2.9 Data quality

Acquiring and processing of measurement data has to be performed with high precision. The level of precision which can be achieved in an online monitoring network mostly depends on sensors and sensor technology on the one hand and measurement conditions on the other hand.

Automatic in-situ measurements usually do not provide the same level of precision as manual laboratory analysis. In the most cases such high precision is not necessary and the precision achieved by automatic measurements is perfectly suitable, though.

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To get the best quality and precision possible from the measurement equipment installed, the monitoring network operator has to utilize adequate quality assurance measures to maximize data quality and precision.

These measures can be:

- Thorough and periodic cleaning and routine maintenance of sensors and measurement equipment.
- Automatic calibration of sensors and use of calibration results in correction algorithms
- Periodic manual reference calibrations of sensors
- Acquiring, recording and interpretation of measurement meta-data (information about conditions on the measurement activity.
- Automatic plausibility checks and correction of measurement values.
- Recording of all measurement value modifications to be able to interpret and reverse them later on if necessary.

The technical complexity and human resources effort to achieve and maintain a high and professional quality standard in an online monitoring network is not to be underestimated. For most tasks listed above, software in the monitoring station and the central station can assist the network operator and reduce the workload for human personnel, though.

Online monitoring network software should provide essential functions for quality control and assurance. Results of plausibility checks and calibration have to be processed automatically and automatic as well as manual data correction functions should be provided.

Information about the quality of each measurement value as well as conditions throughout the measurement process should be available as additional parameters on demand and be taken into account on all data processing, evaluation and presentation activities in general.

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3. Essential Components of an Online Monitoring Network

3.1 Sensor

The sensor (measurement device) is the link between the medium under examination and the IT infrastructure of the online monitoring network, and thus the link between the reality and the model. In a typical online monitoring network, a large number of different sensors and sensor types with specific characteristics for different measurement requirements are used.

3.1.1 Tasks

The most important task for a sensor is the transformation of the physical characteristics of the medium on the sampling location (input signal) into an electric signal which can be processed automatically (output signal) by means of a suitable measurement method. Physical characteristics of the medium, where no corresponding sensor exists (e.g. because there is no suitable measurement method) can only be indirectly integrated into the online monitoring network (for example by manual sampling and laboratory analysis and manual or semi-automatic data recording later on).

Note: it is not the intend of this paper to discuss the manifold characteristics and usage possibilities of different measurement methods.

3.1.2 Interfaces

Output signals of different sensors or sensor types can have different information content and presentation formats. Currently there is no commonly accepted single standard for the data interface of online sensors.

Simple online sensors just provide analogue current or voltage signals which have a (hopefully) linear correlation with the physical characteristics of the medium in which we are interested. These signals have to be converted into digital information before they can be processed by a computer device further on (A/D converter). As the input signals of these simple sensors are just instantaneous values, atomic values as defined in chapter 2.2 (page 4) have to be built at certain points in time, too. Additionally, any well-known non-linearities of the sensor can be taken into account and compensated for by these tasks if needed, too.

Most modern sensors and measurement devices already provide an alphanumeric representation of one or even several physical characteristics of the medium, which can be extracted in machine readable form through some sort of digital computer interface like HP-IB (IEEE488) bus or RS232 standard serial interface. These sensors already provide atomic measurement values or even aggregated values as well as a usually huge number of additional information about the measurement process (like environmental conditions, data quality information, statistical information, etc.) and can be controlled by the attached computer (like performing calibration or cleaning activities, selection of measurement range or measurement methods)

Still there is no uniform interface standard for these kind of sensors. Different manufacturers of sensors use different protocols for the device interface in terms of electrical characteristics, data representation, unit and parameter identification and command set. Integration of different sensors and sensor types is a major challenge when implementing an online monitoring network in general and the network's monitoring stations in particular.

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3.2 Monitoring Station

The monitoring station consists of the infrastructure (hardware, software) placed at or nearby the sampling location which is needed to assist and maintain regular and continuous operation of sensors. The monitoring station is the link between data acquisition and processing of measurement values.

A single monitoring station can usually serve one or several sampling locations.

3.2.1 Tasks

A monitoring station's tasks are manifold, system borders are varying and are not very well defined in general. Therefore it is not easy to exactly describe the tasks of an online monitoring station.

In most cases, the following functions and characteristics can be assigned to the monitoring station's domain with much certainty:

- Stable working conditions
  The monitoring station provides suitable working conditions for the delicate measurement devices (humidity, temperature, radiation, dust, vibration, etc.), provides a stable mechanical and electro-mechanical foundation for the whole measurement process and serves as protection against theft and vandalism.
- Sensor control
  The monitoring station is equipped with several interfaces, depending on the number and type of sensors connected. The monitoring station usually controls the measurement process autonomously, but sometimes allows direct access to some selected sensor functionality on request by an external user (“transparent mode“)
- Measurement process support
  The monitoring station has mechanical and electrical equipment as well as software to support the measurement process like pumps, valves, filters, calibration equipment, etc.
- Pre-processing of measurement results
  Different sensors provide their measurement results in different ways. The monitoring station has the task to process this “raw data“ and convert it into some uniform format suitable for further processing. These tasks include analogue/digital conversion, calculation of raw values and atomic measurement values, quality assurance measures, aggregation, plausibility checks, etc. That way, the monitoring station does the first step to preprocess the data in order to increase the content of information in the whole monitoring network.
- Short-time data storage
  All collected and pre-processed measurement results have to be stored for some time before they get transferred into the central station on request. The size of this storage area has to be sufficient to store all measurement data, additional meta data as well as messages and status information even if telemetry is out of order for some time (usually up to several days of storage capacity is provided).
- Telemetry
  Telemetry functions are needed in the monitoring station for communication with the central station in order to transfer measurement results as well as receive configuration data and commands.

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3.2.2 Components

Depending on application and requirements, the monitoring station usually consists of a combination of several components like the following:

- Containment
  Foundation, Container, anti-theft protection, etc.
- Power supply
  Connection to public (main) energy supply, solar panel, UPS, emergency power supply
- Sensors and measurement devices
  Measurement equipment depending on the measurement task and conditions
- Additional measurement instrumentation
  Pumps, valves, filters, air or water hose, calibration devices
- Monitoring station computer (“MSC“)
  Industrial-grade computer device with hardware, software, interfaces and storage capacity as needed.
- Telemetry components
  Modem, phone line, satellite link, ...

Depending on the field of application, all or some of these components are needed to build the monitoring station.

3.2.3 Variants

As already mentioned the monitoring station's system borders are variable and not always unambiguous. In some applications, a single “intelligent“ measurement device or data logger can perform all tasks needed on site and build a complete monitoring station if equipped together with power supply and a robust containment.

But as soon as several different sensor types are to be used on one or even several sample locations, or if the measurement process needs complex supporting activities, a full equipped monitoring station usually is required to support the measurement process on site.

Sophisticated data pre-processing on-site also requires the installation of intelligent and powerful monitoring stations.

3.2.4 Stability and flexibility

Every non-trivial online monitoring network has high requirements on stability and flexibility of the monitoring stations. Monitoring stations have to operate continuously for weeks without interruption and with the least service effort possible in sometimes harmful environmental conditions.

A complex online monitoring network can consist of up to 100 or more monitoring stations. To reduce investment and operational costs, the network operator wants to use homogeneous and similar equipment for monitoring stations and sensors. As measurement tasks can be very different, the monitoring station has to be designed for flexibility and must be able to be parametrised for the specific measurement task. It is a must for the monitoring station to support different sensors, sensor types and measurement procedures and methods.

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3.3 Central Station

The monitoring network central station is the superior control system for the whole online monitoring network. It uses hardware and software components to control the monitoring stations, collect, process and store the measurement data and provides interfaces to users and external systems. Without a suitable central station an online monitoring network can not be operated.

3.3.1 Tasks

Some of the major tasks and requirements of the central station are:

- Administration and control of monitoring network operation
- Quality assurance and quality control
- Manual data input and correction
- Data evaluation and presentation
- Routine task operation
- Supervision and alert management
- Data storage
- Data transfer and exchange

The central station's position in the centre of the online monitoring network allows the execution of tasks which are impossible to perform at other places in the network (e.g. on the monitoring station). These are tasks in the e.g. quality control or supervision domain, which usually need access to data from several different sampling locations. Long-time storage or presentation and transmission of higher level aggregate values are tasks, which only can be performed by the central station, too.

3.3.2 User Interface

Many functions of the central station require the direct interaction with the user, who initiates and controls activities, queries information and checks the results. For all these tasks the central station has to provide a suitable user interface.

Modern software architecture usually separates the user interface from the application's internal business logic. That way different versions and variants of user interfaces can be implemented, but the application core and functionality remains the same. Additionally, the user interface can be designed independent of operating system and network transparent and so allow a maximum of flexibility and freedom of choice for the end user.

Typical applications of this architecture are:

- Web client
  Allows interactive access to all functions of the application by use of a web browser. On the end user's computer only standard web browser software is needed and all functionality can be accessed even through relatively slow online connections (even through the Internet).

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- Web service
  Allows automatic access to data and functions of the central station for external software by use of network connections and standardized communication protocols.
- Application client
  Interactive access to all functions of the central station works by remote method invocations which are implemented in a special client software. This client software has to be installed on the user's computer and usually has a higher functionality than a web client.
- Database client
  In this application direct access to the central station's database is performed by special software with suitable database support.

Each application method has its specific advantages and disadvantages. A powerful monitoring network central station should provide all or at least some of these methods to provide high flexibility for the network's operator.

It is mandatory that all access methods have to provide some sort of access control to save the network's data for abuse by unauthorized persons.

3.3.3 Special- vs. standard software

Data presentation and routine task functionality is often considered one of the most important parts of the central station software, yet there is usually a lot of discussion about the way it has to be implemented and used. The most controversially discussed question is whether those functionality should be implemented by special software internal to and integrated in the central station itself, or if external standard software can and should be used for this task.

Currently available standard software for data processing, evaluation and presentation has reached a high level of functionality. The selection of standard software available is amazingly manifold and covers everything from graphical data presentation software to statistical as well as “data mining” software packages.

Standard software, on the other hand, is more than often very generic and usually does not handle special but still important requirements of environmental monitoring data evaluation and presentation applications like the consideration of several different threshold limits, special aggregation algorithms or different criteria for the validity of data.

Mandatory requirement for the use of data processing standard software in online monitoring networks is a database allowing adequate use of algorithms and functions of the software. Data processing functions are worthless if algorithms are fed with invalid data or if the validity of records is not considered in the right way. It is therefore important to have full and optimized access to all data and attributes describing the measurement results when processing measurement data by external software. The definition of adequate, correct and still fast queries is not a trivial task and is not to be underestimated.

Software designed and implemented specifically for the use in environmental monitoring networks can usually meet all these requirements much better and with higher performance.

For these reasons, online monitoring networks central station software usually has it's own set of specialized functionality to perform routine tasks and basic data processing, evaluation and presentation, and provides interfaces for external standard software to perform further presentations and reports not covered by the internal software.

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3.3.4 Availability

As the central station is the most important part for the operation of the online monitoring network, the availability of this system is one of the most important operational parameters.

Usually, the central station is operated around the clock (“24x7x52“) without or with only minimal interruption (“downtime“). In some applications, system downtime of more than one hour or less in a year can not be accepted, resulting in availability requirements of 99,98% or better.

These values can only be achieved by suitable IT infrastructure like the implementation of a high availability cluster (“HA Cluster“) at corresponding costs. When planning the online monitoring network, the availability requirements have to be thoroughly and carefully considered to implement a system which perfectly fits the requirements at minimal costs.

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3.4 Database

The online monitoring network database is usually an integrated component of the central station, but in some sense an independent system component, too. Communication between database and applications is usually done by network transparent remote method invocations.

3.4.1 Tasks and requirements

A list of requirements for the online monitoring network database contains:

- Stable foundation for the online monitoring network data model
- Administration of data and meta data
- Powerful data access functions
- Powerful data administration and management functions
- High performance for routine tasks

The choice of a suitable database management software as well as the design of the data model is of crucial importance for the compliance with these requirements.

3.4.2 Technology

The database has major impact on the performance of the whole online monitoring network and so the selection of a suitable database technology is of crucial importance.

As of today, the already mentioned requirements can only be met with modern relational or object-relational client-server database management systems. These systems are usually available and installed as separate products and integrated with the central station application software trough well defined interfaces.

It is possible that, in order to meet all requirements on performance, flexibility and availability, high-end technology has to be used like distributed database systems or database cluster solutions.

3.4.3 Selection criteria

When selecting a suitable database management system product, several characteristics and properties have to be taken into account.

Functional requirements are:

- The database management system has to be able to cope with the number of records expected. Depending on the size of the monitoring network, hundreds of millions of data records can be produced and have to be stored in the database of the central station.
- The database management system must be able to support all properties of the selected data model and data model design.
- The database management system must have adequate interfaces for the software of the central station as well as additional third party software.
- The database management system must have adequate interfaces and functions for administration and maintenance of the system in operation.

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Support of the SQL query language as well as modern technologies like transactions, triggers, referential integrity and stored procedures are essential and should be self-evident.

Other, non-functional requirements are of course important as well.

These include:

- Support for existing software
- Existing database know how
- Database costs and license conditions

3.4.4 Dimensioning

Database performance requirements are not to be underestimated. Even for “simple“ immission monitoring networks the amount of data produced can be substantial.

The following parameters are the major contributors for the storage size needed by the database (in bytes):

- Measurement interval
  The number of measurement values by time unit and sample location parameter (SLP) can be derived by this information.
- Number of sample location parameters (SLP)
  This parameter is directly connected to the number of time series which have to be stored in the database.
- Database storage size of a single measurement value
  Here all data which is needed to unambiguously describe the atomic value as well as all additional data linked to the atomic value has to be taken into account.

The measurement interval has to be chosen according to the characteristics of the medium and the measurement task and for a typical online monitoring network usually is somewhere between 1 minute and 1 hour, resulting in 24 to 1440 measurement values per day and sample location parameter. If the online monitoring network also or only has non-equidistant time series, adequate mean values have to be used.

The number of sample location parameters can be calculated by counting all parameters which are measured on all sample locations in the network.

The size of the storage area which is needed by a single measurement value is very much implementation dependent. Depending on the data model, different information is stored for each measurement value like the raw value itself, presentation value, validity flag, marking flags, access control lists and of course the keys needed to identify the value like location and time stamp. From experience one can say that a single measurement value can use up to 100 bytes or more.

Example: one online monitoring network implemented by xS+S with 8 examination areas, 30 sample locations and about 7250 sample location parameters has about 125 million measurement values stored into the database after 18 months of operation. The measurement values take about 13 GB of storage, excluding index files.

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This online monitoring network uses non-equidistant time series with measurement intervals between 3 and 30 minutes, in some cases measurement intervals of 1 minute are used. In this implementation, one single measurement value record takes about 100 bytes of storage size, including a large amount of additional information which is used to further process and interpret the measurement results.

The number of transactions the database has to support per time unit and within a certain response time has an impact on the selection of database hardware, too. Number and nature of database queries have to be estimated in the planning- and conception-phase of the online monitoring network and considered accordingly.

As soon as the network operator wants to provide data access to the public (e.g. through the Internet), performing these estimations usually is very challenging task. The numbers of anonymous access and the resulting peak demand to the database system can not be predicted exactly and can exceed the regular operation demand by far. On the other hand, the response time requirements for Internet data presentation are usually not as high as for internal use.

Experience shows that in situations, where the availability and performance of the system for the network operators technical staff is essential (like in pre-alarm situations), anonymous access to the database through the Internet by the interested public is rising dramatically, also.

For these reasons, the presentation of data to the public via the Internet usually has to be fed by a separate database system, which periodically gets updated by the central database. That way, even under alarm situations, high demand and increasing anonymous access to the data can not compromise the operation of the whole network.

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3.5 Telemetry

Modern data communication technology allows manifold possibilities of communication between geographically distributed, not directly linked communication partners for many different applications. It is not unusual for a single online monitoring network to utilize several different communication methods and technologies in parallel.

3.5.1 Tasks

Main application for communication technologies in an online monitoring network is the data link between the central station and the on-site monitoring stations. In rare cases the central station is directly linked to a sensor. Under certain conditions the monitoring stations use telemetry functions to communicate with sensors, though a fixed link between sensor and monitoring station usually is the case.

Communication between central station and monitoring stations mostly is used to transfer measurement results from the monitoring stations to the central station. Additionally, configuration information as well as control commands are transferred from the central station to the monitoring stations.

3.5.2 Technologies

Data communication methods are usually described by a layer model like the ISO/OSI 7 layer model or similar. By implementing a simplified layer model in an online monitoring network the following communication layers can be identified:

1. Hardware layer
   Describes the physical characteristics of the communication medium and communication hardware equipment (e.g. modulation process, electrical characteristics, physical dimensions, ...)
2. Transport layer
   Responsible for reliable transfer of data and data packets between communication partners (e.g. addressing, error handling and correction, packet retry, timeout handling)
3. Presentation layer
   Defines the layout and structure of data and command packets in the data stream (e.g. data format, packet length, ...)
4. Application layer
   Defines the semantics and interpretation of data packets exchanged between the communication partners (e.g. interpretation of labels and numbers, reaction on certain control packets, ...)

There are a number of technologies available to implement each of these communication layers.

Typical examples for each layer are:

1. Hardware layer
   Analogue or digital grid-bound dial-up connections and data communication equipment (analogue modem, ISDN terminal adapter), wireless digital dial-up connections using public communication infrastructure (GSM), radio modem, leased-line, Ethernet

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2. Transport layer
   Different point-to-point communication protocols (e.g. DIN66348), packet oriented, routable protocols (e.g. TCP/IP)
3. Presentation layer
   Standardized protocols (e.g. DDP), various remote procedure call protocols, XML, protocols specifically designed for the requirements in online monitoring networks
4. Application layer
   Mostly specialized protocols, depending on the requirements and functions in online monitoring networks

Protocol layers 1 and 2 are responsible for the transport of raw digital information in an mostly application independent way by using existing or specifically installed communication infrastructure. When implementing an online monitoring network one has to take into account that it is not always possible to deploy or use a completely homogeneous communication infrastructure at reasonable costs. It is therefore important to have system components which are flexible and can easily cope with different communication technology.

From protocol layer 3 and above data communication protocols are becoming increasingly application specific. Currently there is no single communication protocol standard which is commonly accepted and meets all requirements. Past attempts to establish such standards (e.g. “Deskriptives Datenprotokoll” (DDP)) so far did not reach wide acceptance and struggle with the speed new technologies, methods and functional requirements find their way into modern online monitoring networks.

It should therefore be the strategy of online monitoring network operators to gain and increase flexibility and freedom of choice by using open and standardized protocols at as much communication layers as possible. Communication subsystems should be modularized, parametrized and exchangeable to provide flexibility even if specialized protocols have to be used.

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4. Summary

Online monitoring networks can be successfully deployed and established in all situations where continuous and simultaneous data acquisition with short measurement intervals and many geographically distributed sample locations, together with high timeliness of measurement results is required. With increasing number of sample locations and decreasing length of measurement intervals, online monitoring networks are the only sufficient technology available today.

By operating online monitoring networks new possibilities for continuous surveillance of large geographic areas, process control and quality assurance are available which can not be achieved with traditional laboratory analysis or at very high costs only.

Online monitoring networks require adequate measurement methods and sensors which are sufficient for the measurement task and able to perform automatically with high precision over a long period of time. Today, online sensors exist for a large number of physical parameters, but they do not exist for all parameters which might be of interest for the end user. Here, manufacturers of online sensors are asked to develop new methods and technologies to fill the remaining gaps.

An online monitoring network is a complex system and requires the cooperation of many and different components from the information and measurement technology domain. Implementation and operation of an online monitoring network is not a trivial task and has to be thoroughly planned and designed and requires long-term commitment of all parties involved.

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