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SENSORS NETWORKS FOR PETROLEUM DERIVATIVE POLLUTION MONITORING SYSTEM

Keywords

Measurement systems, petroleum derivative pollution, hydrocarbon pollution, monitoring systems, wireless measurement systems, sensors networks.

Abstract

This paper discusses the solution of the www petroleum derivative pollution monitoring system. The main aim of this paper is to present the authors' approach to the very current problem of the practical realisation of the www, server based, measuring system. The idea of the system is based on collecting data from mobile GSM/GPRS accessed observation points (MOP), and delivering information on potential pollution to the authorised www clients. Data transfer between MOP and the clients is controlled by the www server. Two types of dedicated MOPs are discussed, based on microcomputer PC 104+ and on microcontroller ADAM 4500. Two different approaches to server realisation are presented: Windows oriented based on Visual Studio. NET, and WAMP oriented, based on the open software.

Introduction

One of the most important problems in environmental pollution protection is the monitoring of the concentrations of petroleum derivatives in fresh water or drainage. For one year at the Warsaw University of Technology, the www petroleum derivative pollution monitoring system was being developed. The aim of the proposed system is to protect sensitive country areas from this kind of pollution with the use of GSM/GPRS accessed mobile observation points (MOP). The basic version of the MOP is equipped with the GPS position locator, sensitive hydrocarbon contamination probe and a GSM/GPRS connection with a central www accessible server.

The dedicated system server collects data from mobile GSM/GPRS accessed observation points, and delivers it through the Internet the information on potential pollution to the authorised www clients. The moving observation indicates property, and the countrywide GSM operator coverage makes the system flexible and universal, allowing for "on request" installations of MOPs in pollution sensitive areas. The structure of the measurement system is presented in Fig.1.

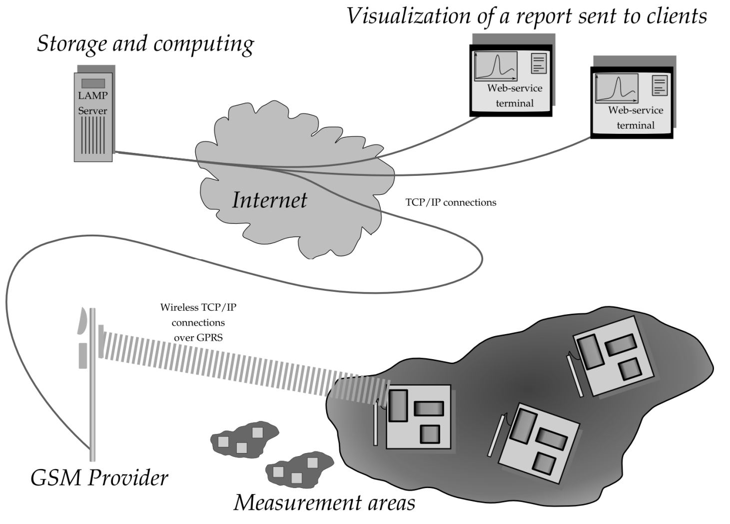


Fig. 1. WWW system structure with mobile observation points

The server has direct GSM/GPRS links with mobile observation points, updates its database with current observations and assures the www access to the authorised clients. Additionally, the server, in emergency situations, can use additional direct links to inform the persons on duty of environment pollution. The presented system can be installed on natural waters, communal sewers or sewage treatment plants. The other important applications are industrial sites, like oil refineries, petrochemical industry areas and harbours.

The system consist of the central server and the clients with the www access, which can be based on any kind of PC, any operating system (Unix, GNU/Linux, Windows) and any kind of server software (Apache, IIS or dedicated server). The server and clients work in comfortable, office conditions.

On the other side of the system there are numerous mobile observation points, which work in heavy duty, open air, field conditions, with autonomous power supply sources (alkaline/solar batteries) and under installation/maintenance cost restrictions.

The server is not a great challenge here, since it forms a standard but specified task oriented solution. Two approaches to server realisation are now developed in parallel: one with the use of Unix or GNU/Linux environment and the Apache server with PHP module, and the other, Windows oriented, based on Visual Studio .NET and the IIS server. Two versions of mobile observation points are actually build and verified:

- One based on the industrial PC-104 computer,
- One based on the specialised CPU (ADAM-4500).

Such an approach allows building the fundamentals of the flexible system from which, in the final stage of development, the development team will focus on the best subset of elaborated solutions.

1. Mobile observation point

Two versions of the mobile observation point (MOP) are based on the same intelligent RS-485 controlled hydrocarbon contamination probe, GSM/GPRS module, and RS-232 controlled GPS receiver (Fig. 2). The standard interface of peripherals allows for easy replacement of the MOP controller.

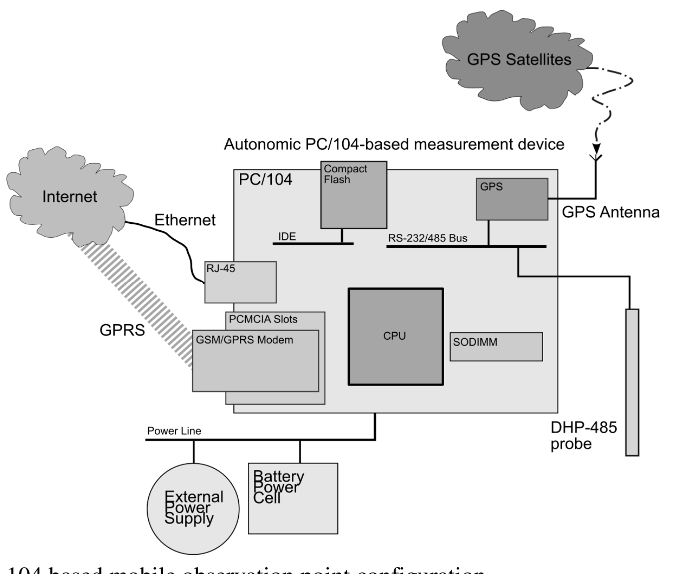


Fig. 2. The PC-104 based mobile observation point configuration

1.1. Measuring peripherals

In a basic version of MOP, the microprocessor's controller controls all three main peripherals: hydrocarbon probe, GPS receiver and GSM/GPRS communication module

Hydrocarbon probe

From the ecological reasons, the measurement of petroleum derivative products' concentration in water is interesting in the limited range from 0 to 100 ppm. The applied probe should not be sensitive to other kinds of pollution and changes in temperature. A very limited number of commercially offered probes fulfil such conditions.

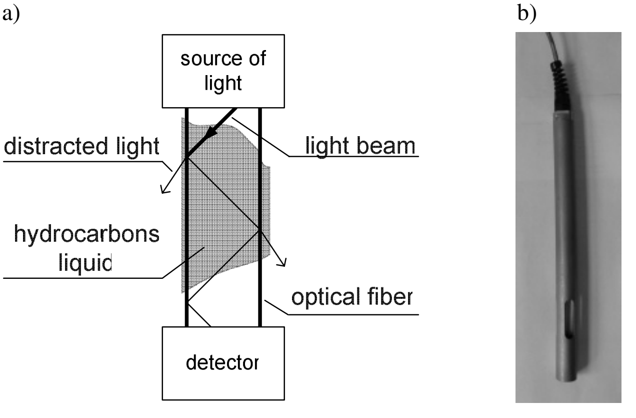


Fig. 3. Digital hydrocarbon probe DHP-485: a) principle of operation, b) commercially available DHP-485

The DHP-485 (digital hydrocarbon probe) made by FCI Environmental (USA), is implemented in the project and has the required parameters (Fig. 3). It can be used in liquid and vapour environments. The FCI probe operation is based on a proprietary coated optical fibre. The refractive index of the coating changes when hydrocarbons are present in the surrounding environment. This results in a measurable loss of light signal as it propagates along the fibre (Fig. 3a). The described probe is sensitive to hydrocarbons with 6 or more carbons, and it is more sensitive to aromatic hydrocarbons. The probe is not sensitive to low molecular weight alkanes (less than 5 carbons), and it has no sensitivity to methane. FCI's proprietary chemical coating allows a reversible response in minutes to increasing or decreasing levels of hydrocarbons [1].

The probe measures the response of the signal and reference beam with the use of photodetectors. A light transmission ratio is calculated excluding ambient light and ambient temperature. A measurement is then performed to distinguish between vapour and liquid surrounding environments. Finally, for the given medium type, a chemical concentration value is calculated by scaling the change in the transmission ratio from previously recorded zero concentration values using the previously calibrated and temperature corrected chemical sensitivity.

The probe is calibrated to p-xylene: therefore, a quantitative measurement in parts per million equivalent to p-xylene is obtained. When analysing other known hydrocarbons, a multiplier may be used to convert the p-xylene equivalent reading to ppm of the known hydrocarbon. The probe measures the ambient temperature and media type (vapour or water), and the concentration is computed from the light loss accounting for known temperature dependencies and chemical sensitivity factors [1].

The theoretical measuring range is from 0 to 2000 ppm with the resolution of 0.1 ppm, with the measurement accuracy in the range 10% of reading. The practical, experimentally confirmed, range is 3÷2000 ppm. The power consumption is very low (200 mW). The response time to step excitation is in the range of 15 minutes.

The probe is equipped with the RAM buffered communication RS-485 channel. The communication with the probe is based on simple command–response protocol. The initialising command has to be sent to the probe to start the measurement. In the answer, the probe sends information that measuring cycle has been terminated, and the measured data can then be read. The measuring cycle can be repeated 3 times a second; however, due to physical and chemical processes on the fibre surface, the accurate information on the hydrocarbon concentration is known after 13–18 minutes. The response time depends on measurement conditions (e.g. the speed of media flow).

The dynamics of the probe was tested by the authors. The probe was moved from the clean water (0 ppm) to a standard sample concentration (180 ppm), and after 18 minutes moved back to the clean water. The probe response is presented by Fig. 4. The probe quickly reacts to changes in concentration, but a stable and final result is obtained after several minutes.

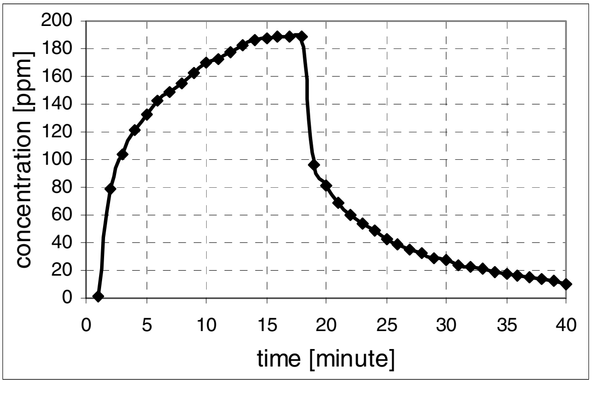


Fig. 4. Dynamic characteristic of hydrocarbon probe

The calibration of the probe is required before its first use. It was verified that the best results were obtained when the point of calibration lies in the middle of the measuring range. If the concentration levels surpass the point of calibration by several orders, the response is non-linear and measurement errors can reach 50% of the measured value. In the project, this problem is not really serious, because concentrations in the range of 200 ppm are reached very rarely, usually during ecological catastrophes. The typical expected measurement range, in standard contamination situations, is 1÷50 ppm.

GPS position locator

Information on the current position of measuring probe in terrain and the time of measurement form complementary data supplied by the GPS receiver ORCAM-20, which is based on SiRFStarII technology (Fig. 5). The best accuracy of the assignment of position is 10÷15 meters. Such accuracy is satisfactory for the perspective application. The receiver communicates with the central controller across the serial port under protocol NMEA-0183, which is the standard data format in text ASCII created by National Marine Electronics Association (USA) to transmit data among navigation attachments.

Fig. 5. GPS receiver ORCAM-20 and antenna

GSM/GPRS communication channel

Communication between server and MOPs is assured by GSM/GPRS terminals with the use of the Motorola g20 modem (Fig. 6). The modem has built-in hardware TCP/IP protocol support with omission of the lower layer of transport data. The MOP controller communicates with g20 through the RS-232 interface. The controller orders the module to log-in on the remote server. After the logging, the controller sends the measuring data with a top speed of 48 kbit/s with the MOP working as a workstation in the www. This workstation has a dynamic (or fixed) IP address for which the GSM operator is the internet provider.

Fig. 6. GSM/GPRS terminal – Motorola g20 and SIM card

1.2. PC-104 MOP solution

The diagram of the PC-104 based MOP solution is presented in Fig. 7. PC/104 is a well-defined standard used in many embedded solutions [2]. It has a great advantage of being in almost full compatibility with Intel's 32-bit architecture specification [3]. Thanks to this compatibility, the same development environment and similar software solutions as in typical personal computer can be used in the project development. It is commonly known that PC/104 based products have a larger size and power consumption as compared to other embedded solutions (like these based on ARM microprocessors for instance). The main reason for the use of PC-104 standard is its ability to create highly scalable and easy to enrich equipment that can operate in a hostile environment.

In presented solution, the PC/104+ all-in-one single board computer PCM--3370 with a low power consumption microprocessor - Intel ULV Celeron 650 is used. The processor has a 650 MHz clock, which is much more than it is needed for the design. Spare computing power can be used to provide distributed solution support of any kind, not particularly related to our problem. The chipset of the board supports Ethernet and video graphics on LCD or CRT. These two capabilities can be used in laboratory development, as in local user interface or in branching the product to a different, more complex tasks.

As in a typical computer there are two main memory types: RAM and a hard disk. The RAM is exactly the same as that used in laptops: popular SDRAM SODIMM up to 256 MB in size. There are two types of non-volatile storage that can be used as hard disks and both are accessible via an IDE bus. One of them is a typical hard disk for personal computers but, due to its spinning parts, the disk-on-chip is preferred in this sort of design. The PCM-3370 supports a Compact Flash that has no spinning parts and has good performance. An industrial type of the Flash is used in this project. The capacity of this media will be as scaled down as much as possible in order to reasonably lower costs.

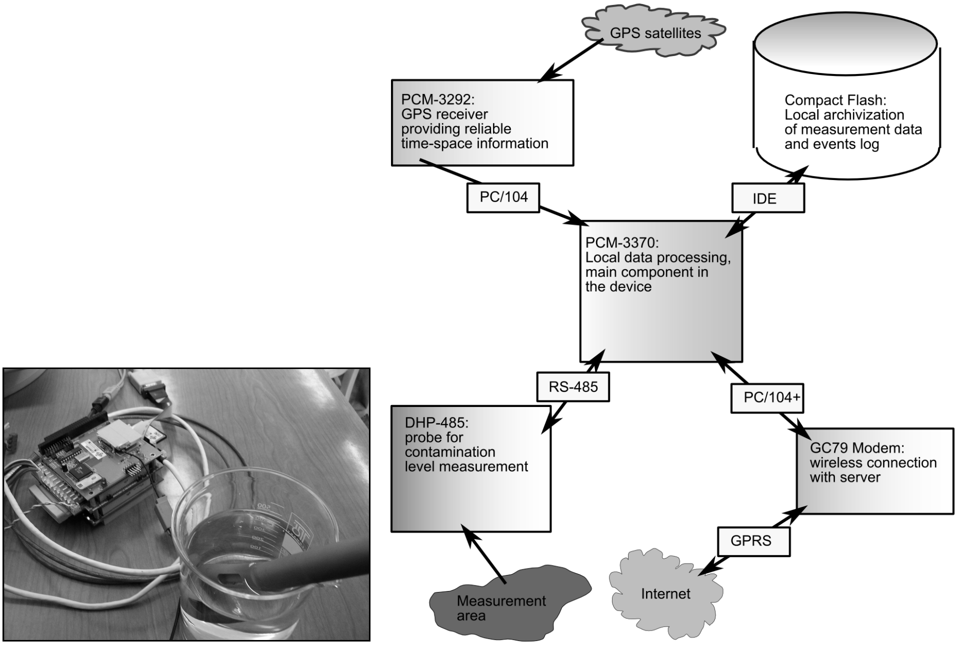


Fig. 7. Mobile Observation Point set based on PC/104+ (left) and information flowchart (right)

Tests of the CF made with the hdparm tool indicated that “Timing buffered disk reads” are about 5.96 MB/s and that “Timing cached reads” are about 344.00 MB/s, which is comparable to the same characteristics of disks in personal computers. In Fig. 7, the Mobile Observation Point set, based on PC/104 is presented. The Linux kernel and some additional software are installed on the device. Additional software, especially targeted for this project, is under development. The final system is designed as a specialised distribution derived from Debian, but some design concepts will be taken from Slackware Linux. The distribution is intended to fulfil embedded Linux standards [4]. The task oriented kernel, fitting only the project needs, will be recompiled.

The PCM-3370 has a standard Ethernet support and the interface. In the current application, it is replaced with the PCMCIA GPRS/GSM modem card, with wireless connection to the Internet. Thanks to the pcmcia-cs and ppp package distributed with Linux, communication with the modem is very easy. There was no problem with drivers, because the popular Ricoh chipset is used in the modem. Data is transferred from nodes to the central server and visualisation clients.

1.3. Specialised CPU solution

As the alternative to the PC-104 MOP solution, the inexpensive, dedicated, controller ADAM 4500 based realisation of the MOP has been developed. This computer is a fully functional stand-alone controller designed to work in hard climatic conditions. It has low computing power but is still sufficient to the project needs. ADAM 4500 has an 80188 processor, 170 kB flash memory and 234 kB RAM for use, and it is equipped with three communication ports: RS-232, RS-485, the third one which can be configured for RS-232 or RS-485. The communication of measuring devices with the controller is very simple, because the measuring probe has an RS485 interface, and the GPS receiver and the GSM/GPRS modem have RS-232 links. The advantage of the ADAM 4500 is its low power consumption and built-in, DOS-like operating system. Fig. 8 shows a Mobile Observation Point set based on ADAM 4500.

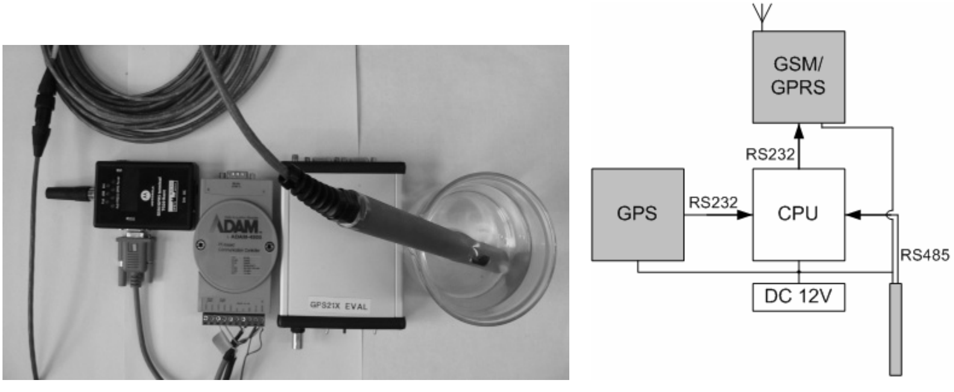


Fig. 8. Mobil Observation Point set based on ADAM4500

The flexible MOP solution allows for the easy replacement of the controller. It has only to have the RS-485 and RS-232 interfaces and the sufficient computing power. The PC-104 and ADAM4500 approaches form the extreme examples of the advanced (expensive) and simple (inexpensive) MOP solution. As an additional proposition, the ADAM6500 (Advantech) and I-7188 (ICP DAS) can be considered. ADAM 6500 is a direct successor of ADAM 4500, it implements 32-bit Intel StrongArm 206 MHz processor and 32 MB memory and has one Ethernet port and five communications ports: 3xRS-232 and 2xRS-485. For the transfer of data from the CPU to the server, we can use the Ethernet port and the TCP/IP protocol.

1.4. Prediction procedures for DHP-485 probe

Applying the prediction algorithm for the sensor characterised by such large time constant like DHP-485 probe can be a reasonable solution. When the prediction algorithm is suitably well chosen, it is possible to minimise the time constant according to the user's expectations. Prognosis has less precision than completed measurement, but it usually is enough for an emergency service. The selection of prediction algorithm depends on kinds of measurement processes. If the dynamic characteristic is stable, after a few measurements it is possible to evaluate a mathematical model of measurement process. Then it is allowed to be used for direct prediction. The idea of this algorithm is presented in Fig. 9a. The algorithms direct prediction consist of three steps [5]: build data base, calculate the mathematical model of measurement process and create prediction algorithm.

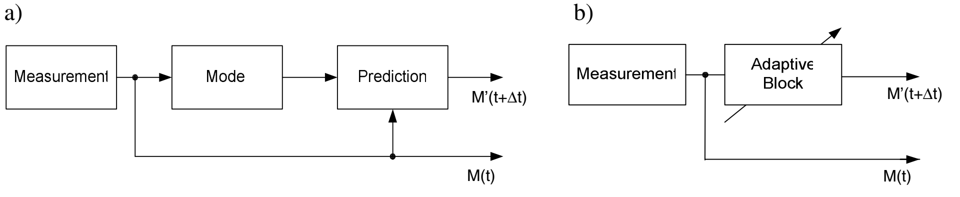


Fig. 9. Block diagrams of the predictions algorithm: a) direct prediction, b) adaptive prediction

If the measurement process has a regressive mathematical model, variable in time, it can be necessary to use adaptive prediction. Fig. 9b presents the idea of this algorithm. During the adaptive procedure, all parameters are constantly adapted and optimised for a given measurement process. Both prediction algorithms were applied for data obtained from the DHP-485 probe. Probe DHP-485 has stable time characteristics, especially when the hydrocarbon concentration is raising and a mathematical model of the measurement process can be rather simple:

$$M(t) = A(1 - \exp(-t/\tau)) \quad (1)$$

Optimal coefficients A and τ in equation (1) were calculated using LS (Least Squares) criterion. Fig. 10a shows the results of direct prediction for data taken from the DHP-485 probe once every minute. This kind of prediction procedure gives a good forecast of the measurement results after two minutes. The error of prognoses is presented on Fig. 10b. It is possible to reduce the response time of the probe to one minute, if the date will be taken from probe much more frequently, for example, every 10 seconds.

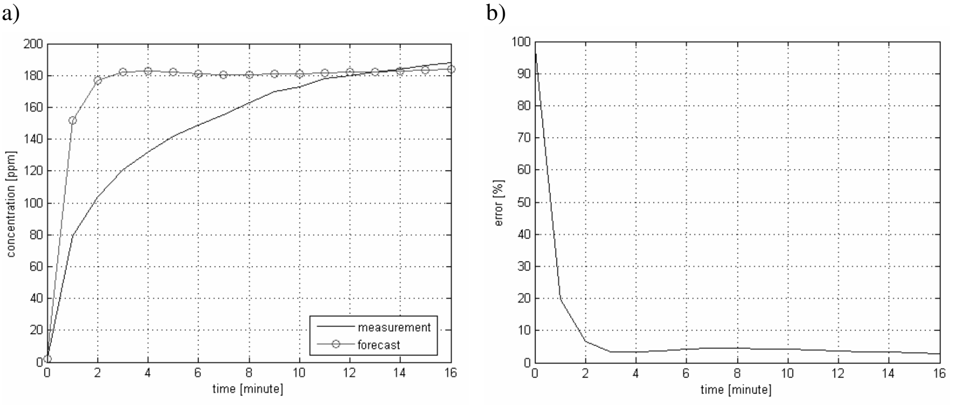


Fig. 10. Measurement results and prognosis for: a) DHP-485 probe, b) prognosis error

When the hydrocarbon concentration is varying in time, the adaptive prediction gives the best result. As a tool for this algorithm, a neural network with feed-forward back-propagation was used. The selected network has two layers, one input-neuron and one output-neuron. A source of success for this approach is the large and diversified database with measurement data. At the current stage of the research the date base is build. Fig. 11 shows the preliminary results of the neural networks approach for one teaching set only, because only two first points were taken in to calculation for input data.

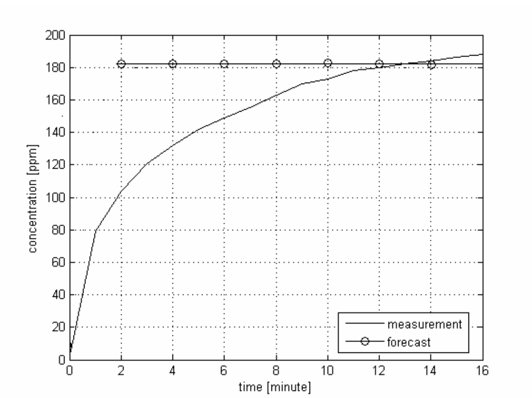


Fig. 11. Forecast and measurement (adaptive prediction)

2. Web system organisation

The MOPs, and their GSM/GPRS links form the hardware part of the whole system (Fig.1). From the clients point of view, the system is the Internet/Web application of the distributed system. Measurement devices (MOPs) are its terminals that are relatively autonomous, although they can be controlled by the central server in some manner. These facilities work autonomously most of the time, but the server can order them to perform particular duties from time to time.

The central point of the system is the server responsible for the overall system functioning. Two different approaches to server realisation are under investigations: Windows oriented based on Visual Studio.NET, and WAMP oriented, based on the open software.

2.1. Windows system approach

The Windows Visual Studio 2005 offers great flexibility in web applications development with the use of ASP.NET. The Windows Visual Studio IDE forms an interesting alternative to Unix web development tools, as it has direct access to the Windows GUI and databases. The web IIS server, which runs the application, can be installed on Windows XP as well as Windows Server 2003 operating systems. The additional advantage of the Windows approach to server realisation is the Visual Studio ability to program web services on mobile platforms. With the ASP Mobile Application Development the alarm situations can access mobile phones and palmtops to assure a quick response to abnormal situations. The authentication and authorisation measures assure the security of web applications.

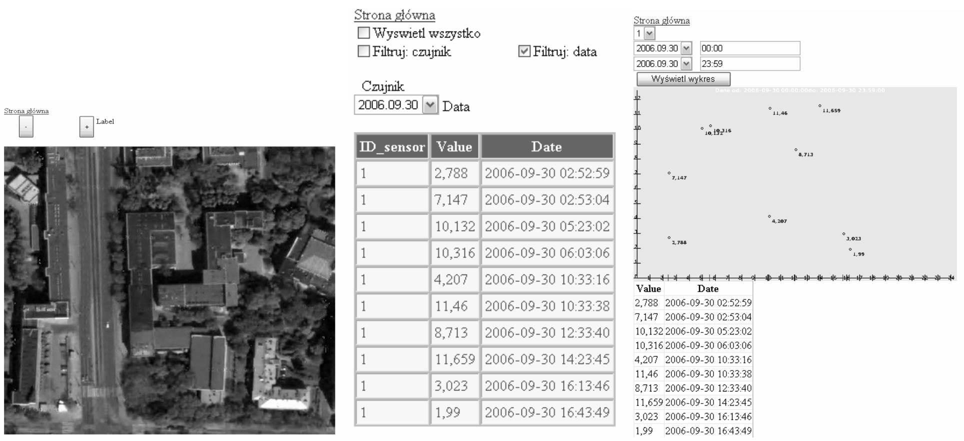
Main assumption was that the application is web based – server - then client, which would allow everybody to get information from every place and every operating system. The first element is a server, which main role is to receive from MOPs the series of measurements, which are intercepted by a special listener. A server with a listener function is based on Windows 2003 and is created as a special Windows service. The listener listens on an earlier defined socket (port and address), receives incoming strings, parses them with a special algorithm, and stores the parsed portions of data in the database (MSSQL 2005 Express Edition) [6]. The database is located on the same machine as the listener, but can be located wherever. The only limitation is to have an Ethernet access. In the database, all data is stored with all supplementary information: from which MOP it is when it was delivered from the MOP, what was the value of measurement and finally, and what is the location of MOP obtained from the GPS module. All this data are used by the IIS Web server, which dynamically creates all pages to the supervisor client's (SvClient) requests. Script language used here is ASP.Net version 2.0 [4].

In current software realisation, when the user (SvClient) launches the web page, he gets three choices of getting different statistics and information on the MOPs:

– The first choice is the location of MOPs, presented on the map, with hotspots on current MOP positions. Currently by clicking on the MOP, the additional information on MOP geographical position is obtained. In further development, a new page can be opened with any kind of graphical/textual information.

– The second option is to get the measurement results and supplementary data for every MOP. The data can be filtered for the chosen MOP or/and chosen date. Filters are created from a dropdown list, which is created from the database using a server-stored procedure. The required data is presented in the form of nice looking tables.
– The third option allows for data to be drawn in graphical form for a chosen MOP and a defined time. The MOP is chosen from a dropdown list, the start and the end time need to be entered by the user.

Further development can deliver web based panels, which can be used to administrate MOP, i.e. disable measurements, change the system sampling rate, enabling measurements, etc. The typical view of the client screen of the .NET environment system is presented in Fig. 12.



ID_sensor	Value	Date
1	2,788	2006-09-30 02:52:59
1	7,147	2006-09-30 02:53:04
1	10,132	2006-09-30 05:23:02
1	10,316	2006-09-30 06:03:06
1	4,207	2006-09-30 10:33:16
1	11,46	2006-09-30 10:33:38
1	8,713	2006-09-30 12:33:40
1	11,659	2006-09-30 14:23:45
1	3,023	2006-09-30 16:13:46
1	1,99	2006-09-30 16:43:49

Fig. 12. The client screen of the .NET environment system

2.2 Unix or GNU/Linux system approach

Realisation of the system server is based on free and open-source applications stack called LAMP (Fig. 13). Usually LAMP is used as an abbreviation for cooperation of Linux operating system, Apache web server, MySQL database and PHP language. According to tests performed by the Coverity project in collaboration with Stanford University on contract with US Department of Homeland Security, LAMP code has significantly fewer errors than other tested software [7]. Therefore, it was considered as a reliable software and a good choice for the basis of the system.

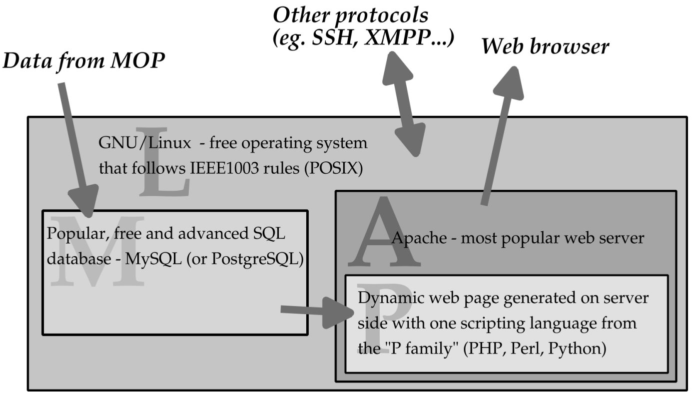


Fig.13. Realisation of the server based on LAMP technology

The main component, which also integrates the measurement system as a whole, is its web server. The Modular "Apache" server from The Apache Software Foundation is used in this solution. It is the most popular web server on the Internet, and, moreover, it is distributed as an "open-source" application under the terms of "free license". Web application is developed with server-side, object-oriented scripting language PHP, which is running as a module for Apache. The web server, after accepting requests from clients, serves them dynamically generated web pages. Therefore, this solution can be considered as a lightweight web-service and probably will evolve in this direction.

Flexible connection between all kinds of system components is established on-demand over the GSM network with GPRS packet data transfer service. MOP can communicate with a web server connected to the Internet thanks to the TCP/IP protocol layered over GPRS. MOP connects to server periodically and transfers last unsent collected measurements with home-grown protocol. Software running on MOP can also indicate that the value of hydrocarbons exceeds assumed limits and switches to "emergency mode". In this situation, the last collected data set is being send immediately. After this, connection is not dropped as usual, but transmission of continuous measurements turns into instant mode.

Connection with MOP cannot be initiated from the server, because the MOP is considered autonomous. Therefore, any maintenance task, such as turning device from/to instant transmission, can be performed only in the time window when the MOP established connection.

The system is designed to monitor the environment for critical events and the growth of such disasters, such as an oil leakage, so keeping every device up to a global time from single clock is important. Uniform timestamp from GPS is used as one of fields in the protocol. In the distributed environment of this adhoc measurement, the exact position of every device is also important. This is the second value from GPS that is transmitted by the devices. XML technology is used in the internals of protocol, so there is no trouble with expanding the system with a new kind of device having different functions. Internal synchronisation problems of MOP software are being solved with standardised [6] and the well-known Unix style.

All data received by server from MOPs is stored in a relational SQL-based database. The developed system runs with the very popular MySQL database. Other databases, such as the powerful PostgreSQL, can be used. The only condition is that there exists a programming interface from language that generates web page to the database. In the presented system the PHP and MySQL are extensively used. Information from system is provided to users in a style of reports generated dynamically on the server-side by the application written in PHP. Therefore, access to system is possible from every place on the Internet with a simple web browser. Despite it being widely accessible, it is also secure, thanks to SSL and authentication. The format of the reports on web pages is adjustable for every user, because the account data is also stored in the database. The web application can create graphical reports, such as charts and plots, with specialised libraries GD or GraPHPite. These reports also include maps that make the results more readable. The device positions, measurements, timestamps and the value of contamination are considered and drawn graphically. Alert information about certain levels of pollution can also be supplied via GSM network with SMS messages sent directly to the mobile phones of emergency groups and operating personnel.

Conclusions

The presented paper described the www petroleum derivative pollution monitoring system that is under development at the Warsaw University of Technology. The idea of the designed system, based on collecting data from mobile GSM/GPRS accessed observation points (MOP), and delivering the information on potential pollution to the authorised www clients. Data transfer between MOP and clients is controlled by the www server. Two types of dedicated MOPs were described, based on microcomputer PC 104+ and microcontroller ADAM 4500/6500.

Two approaches to server realisation were discussed: one with the use of Unix or GNU/Linux environment and the Apache server with PHP module, and the other, Windows system targeted, with the IIS server. At the current stage of the project, both approaches are realised in parallel. The final selection depends on the end-user's expectations and economic restrictions.

Acknowledgements

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References

1. User's manual DHP-100 & DHP-485 Digital Hydrocarbon Probe, FCI ENVIRONMENTAL, INC. 1181 Grier Drive, Building B, Las Vegas, Nevada, 199.
2. PC/104 Specification Version 2.4. August 2001, PC/104 Embedded Consortium.
3. IA-32 Intel® Architecture Software Developer's Manual. Intel Corporation 2005.
4. Yaghmour K.: Building Embedded Linux Systems. O'Reilly Media, 2003.
5. Bielinska, Figwer: Analyze identification and prediction time sequence. Slask University of Technologies. Gliwice, 1995.
6. The Open Group Base Specifications, Issue 6, IEEE Std 1003.1, 2004, The IEEE and The Open Group.
7. Measuring software quality: A study of open source software. Coverity, 2006.

Reviewer:
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Sieć czujnikowa do monitorowania skażeń produktami ropopochodnymi

Słowa kluczowe

System pomiarowy, skażenia ropopochodne, systemy monitorujące, bezprzewodowe systemy pomiarowe, sieci czujnikowe.

Streszczenie

W artykule przedstawiono system monitorowania skażeń produktami ropopochodnymi, bazujący na sieci WWW. Głównym celem artykułu jest przedstawienie podejścia Autorów do bardzo aktualnego problemu praktycznej budowy systemów pomiarowych wykorzystujących strony WWW i szeroko rozumiany Internet. Idea systemu zakłada zbieranie danych poprzez sieć GSM/GPRS z mobilnych punktów pomiarowych (MPP) i przekazywanie ich za pośrednictwem stron WWW do potencjalnych autoryzowanych odbiorców. Transmisja danych pomiędzy MPP a odbiorcami jest kontrolowana za pomocą serwera WWW. Dwa typy MPP są analizowane, jeden oparty o mikrokomputer PC 104+, drugi bazujący na mikrokontrolerze ADAM 4500. Również są analizowane dwa podejścia do realizacji serwera, jeden bazujący na Visual Studio.NET, drugi wykorzystuje technologie WAMP.