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A HPC (HIGH PERFORMANCE COMPUTING) BASED MODEL FOR OPTIMISATION OF THE WASTE MANAGEMENT SYSTEMS IN METROPOLITAN REGIONS

ZAAWANSOWANY MODEL OPTYMALIZACJI SYSTEMÓW GOSPODARKI ODPADAMI W METROPOLIACH WYLORZYSTUJĄCY RÓWNOLEGŁĄ ARCHITEKTURĘ OBLICZENIOWĄ

Abstract

The article presents the conception of an intelligent system for monitoring and managing the municipal waste disposal in metropolises. Applying advanced IT solutions using intelligent computational techniques enables the passage from the passive position of self-government units (JST) in managing the waste disposal to the active position, especially in decision making during the problem solving of planning systems associated with the organisation management of the complex infrastructure of the waste disposal. The aim of using ICT systems is an increase in the reliability of the economy of systemic waste, monitoring in real time, the stabilization of the work of the system and the optimization of logistic and technological processes in the context of the raw material, energy application and simultaneously limiting the influence on all components of the environment.

Keywords: SMART City, waste management, predictive models, artificial intelligence, GIS, parallel computing architecture (HPC)

Streszczenie

W artykule przedstawiono koncepcję inteligentnego systemu monitorowania i zarządzania gospodarką odpadami komunalnymi w metropoliach. Zastosowanie zaawansowanych rozwiązań informatycznych wykorzystujących inteligentne techniki obliczeniowe umożliwia na przejście z biernej pozycji jednostek samorządowych (JST) w zarządzaniu gospodarką odpadami do aktywnego działania, w tym szczególnie, podejmowanie decyzji podczas rozwiązywania problemów planistycznych związanych z organizacją systemu zbiórki i systemu transportu odpadów i kompleksowym zarządzaniem złożoną infrastrukturą systemów gospodarki odpadami. Celem wykorzystania systemów ICT jest zwiększenie niezawodności systemów gospodarki odpadami, monitoring w czasie rzeczywistym, stabilizacja pracy systemu oraz optymalizacja procesów logistycznych i technologicznych w kontekście wykorzystania surowcowego, energetycznego przy jednoczesnym ograniczeniu wpływu na wszystkie komponenty środowiska (woda, powietrze, gleba).

Słowa kluczowe: SMART City, gospodarka odpadami, modele predykcyjne, sztuczna inteligencja, GIS, równoległa architektura obliczeniowa (HPC)

1. Introduction – Diagnosis of the market – identification of the needs of local government units in managing waste disposal systems

Transformation of global economies towards effective using natural resources and lowering the release of pollution emissions, incl. greenhouse gases, is becoming one of civilization's key challenges. The negative consequences of climate change or irreparable loss of natural resources, and the lack of integrated actions are manifest already in the near future and are forcing us to take advanced of procedural, technological research on drawing new solutions assisted with ICT systems.

Waste disposal in connection with energy management and low-carbon is establishing the integrated system of action in using all advanced technologies. Implementing effective, technologically advanced solutions in all areas, in the context of reducing the power consumption and materials, is of key importance in increasing the use of renewable energy and introducing environment-friendly technological innovations. The actions to be taken are determined by an adopted strategy for limiting the climate change in global warming. The national economy is being shaped by interpenetrating sectors of the scrap, water-sewage, transport and municipal energy management. The solution suggested by the authors is a response to contemporary challenges in the context of the rapid development of intelligent cities (SMART Cities) in the area of balanced managing the municipal infrastructure in metropolises, including the balance of resources, in the context of increasing the effectiveness of resource use.

The decision support system constituting the central element of the target computer integrated solution fulfils the strategic objectives of waste disposal established in the provisions of law that allows for the identification of scattered sources of waste, on quantitative and qualitative characteristics of waste generated in dispersed sources, to stocktaking and managing tied objects from waste disposal, as well as for assisting decision-making action on the different territorial reach and for simulations of multi-variants of waste management.

The suggested answer takes into account standards and requirements determined in Directives of the EU and refined trends of the ICT development of systems in strategic priority areas.

The advantage of the proposed system above others operating so far is the element of the intelligence including predicting future events and states of components of the system of the waste disposal in particular. This feature in combination with the self-studying concluding intelligent system is not only used to react to current changes in parameters causing the destabilization of the system, but also to anticipate these changes and with the appropriate advance to correct the functioning of the system preparing it for the predicted development of the situation, which is outweighing specifically in folded infrastructure distributed systems about the great inertia.

The technologically advanced solutions suggested by the authors, i.e. the ICT system of the HPC class (High Performance Computing), with the concluding module included, allows (through analysis of the decision space and of events in real time) for predicting future behaviours of individual system components of the waste disposal and effectively to respond to unknown cases, assisting in taking strategic decisions. The system in question includes advanced tools, mainly on the algorithmic level, for applying new computational technologies (including the possibility of GPGPU/FPGA using for the acceleration calculations, of stream-oriented data processing and multi-variants simulation) in precisely defined models of the space of states and events, constituting components of the database of objects and technological processes of the system of the waste disposal.

In case of the waste market, mass balance is an important aspect of the work of every system, in the context of the demand in raw materials, including the means of conveying the energy in conditions of the appearance of factors causing the destabilization of its correct functioning.

The rapid development of computer and IT technologies is determining the economic development in various sectors of the national economy, and thus close cooperation with scientific bodies is required from entrepreneurs, including small and medium enterprises [3, 5, 8].

Applying advanced computer solutions that exploit intelligent computational techniques enables a transformation from the passive position of local government units (JST) in managing the waste disposal to active action, in particular decision making during the solving of planning systems associated with the organization of the collection system and the system of the transport of waste and monitoring, and comprehensive management of the complex infrastructure of the waste disposal. In order to use ICT systems increasing the reliability of economy systems in waste, monitoring in real time, the stabilization of the work of the system and the optimization of logistical and technological processes in the context of the raw material is needed, energy application while simultaneously limiting the influence on all components of the environment (water, air, soil).

2. Concept of the expert system supporting the processes optimizing management of waste disposal

The Expert system (Fig.1) is based on a predefined component environment – ProWaste Objects .NET, which is one of the ProWasteEnterpriseSolutionFramework .NET environment (author's solution). The real-time HPC (nVidia CUDA) system is a component-oriented environment with a specialized database of knowledge representing the elements of technological processes in the area of water and sewage management, considered as control objects. All variables related to supported devices are updated online through the OPC UA servers of the monitoring and control system. This system creates a platform for advanced algorithm operation, acting as the interface between the control and monitoring systems and the PLC. System configuration ensures permanent monitoring of communication connections and automatic system response in case of a failure, sudden parameter changes, etc. Key performance indicators may also be included in the system, and all calculations required for optimal system performance are performed in real-time using a parallel computing architecture. This advanced multi-parameter control system consists of a main MPC controller and individual MPC controllers for each component device.

The Expert system is based on a process state space model. It is implemented on a higher supervision level in order to manipulate the multiple control loops and to optimize control systems and track changes in process variable values. The state space model is used to forecast the influence of time independent process variables – both manipulated and anticipated – on dependent output variables of the process – so regulated like unregulated predicted variables. The model allows for consideration of the dynamics of the process between the change of independent variables and the expected changes of the dependent variables. The optimization algorithm predicts the future course of the process and compares it to the operating objectives. Internally, the algorithm also calculates the strategy of future decisions, saving only the current changes in the settings of the lower level regulators. This multi-stage computing process, repeated at each execution, enables the driver to plan ahead in order to ensure optimum dynamic control of regulated process variables. EnviroLab.ProWater ensures flexibility in the combination of control targets and control of limits of variable for multiple variables. Each adjustable process variable may contain a target value and/or limiting values limits can be defined as absolute minimum/maximum values or minimum/ maximum deviations from set point values).

One of the main tasks will be to develop advanced prediction control (MPC), adaptive (APC) and inferential control algorithms that will provide:

- Significant reduction in operating costs and higher stability of operating parameters than with classic PID controllers.
- Reduced time for diagnosis and analysis of processes and thus rapid response to interferences and undesired working conditions - through state domain analysis.
- Rapid response to unknown events (interfering signals) destabilizing the technological process. The EnviroLab Enterprise Solution incorporates dedicated HPC (High Performance Computing) tools, advanced prediction models for MPC and adaptive and inferential control and thus provides stable and optimal working performance of the equipment.
- Significant shortening of the design process or modifications of the visualization and process control systems through the use of the RAD.NEnvironT component.
- Significant reduction of process modelling errors, thanks to the author's innovative solutions (predefined NEnviroT intelligent real-time components – processes, objects, events), meaning that all process units can be precisely modelled and optimized to support planning and profit maximization.
- quick adaption of the drivers' operating strategies to economic and environmental goals by using innovative technology in the ProWaste Enterprise Solution. It allows users to adapt quickly to changing economic scenarios, making it easy to design and maintain the driver.
- Significant increase in system performance due to the use of 64-bit architecture
- Real-time knowledge base optimization based on process, computational, and laboratory data
- API to C ++, Java and .NET for individual adapters and direct integration
- Use of Complex Event Processing technology (complex event processing).

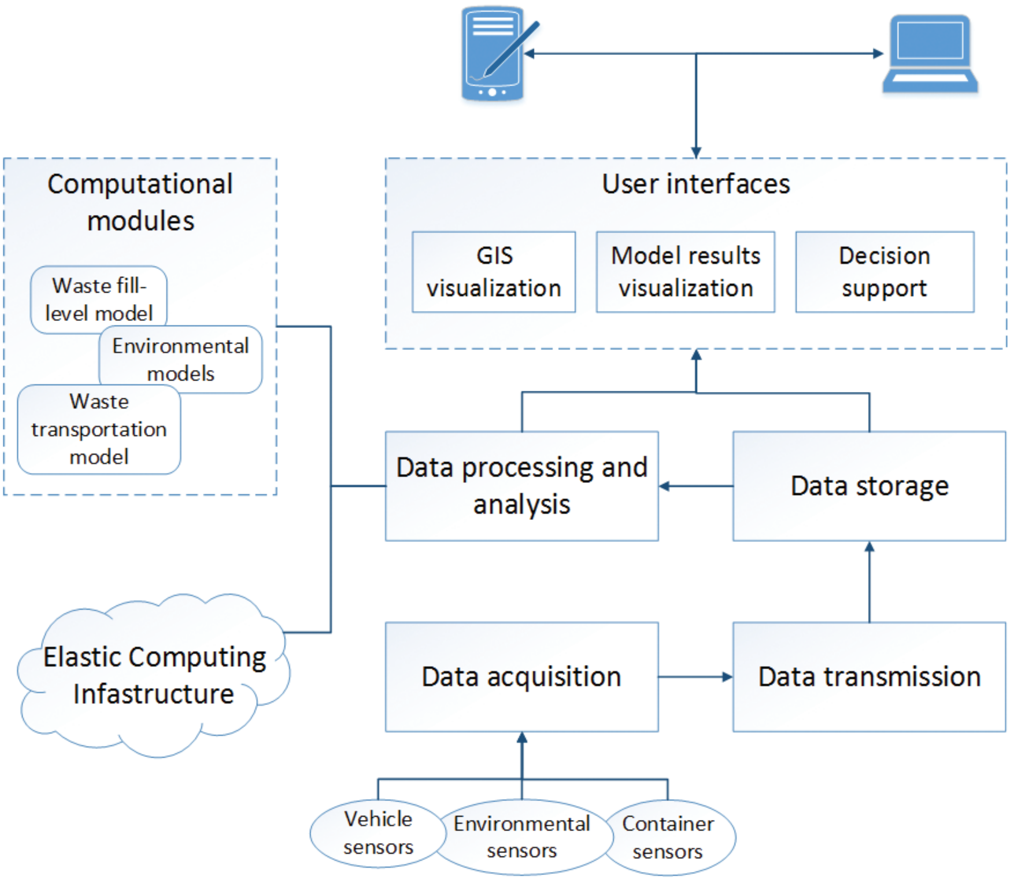

Fig. 1. The Topology of the Expert System

3. The Topology of the Expert System

Control in a hierarchical structure is an effective way to control complex control systems (Fig. 1). In the hierarchical system, the system decomposes into separate subsystems or cells, with autonomous information processing and decision-making. The main reasons for the use of control structures are:

1. The ability to decompose a complex decision problem with a large number of coordinates, the most difficult solution, a few minor simpler decision problems, a smaller number of state coordinates (smaller space of states) solved sequentially or in parallel.
2. Increased flexibility and clarity with modules easier to modify and detect any errors,
3. Shorter computation time (quicker algorithms), thanks to the use of parallel computing architecture
4. Increased reliability of the operation of the control system.

The structure of the hierarchical system (Fig. 2) consists of the main layers (Supervisor, Optimizer, and Follower) and subsystems (slow, medium and fast). Higher levels generate controls and decisions that help the lower layer perform its tasks. Layer separation is the result of functional decomposition of the control system, and subdivision is the result of decomposition of system dynamics in the time scale. In addition, it is uses the available information about the system such as dynamics and interactions between its individual elements. (knowledge base on control objects).

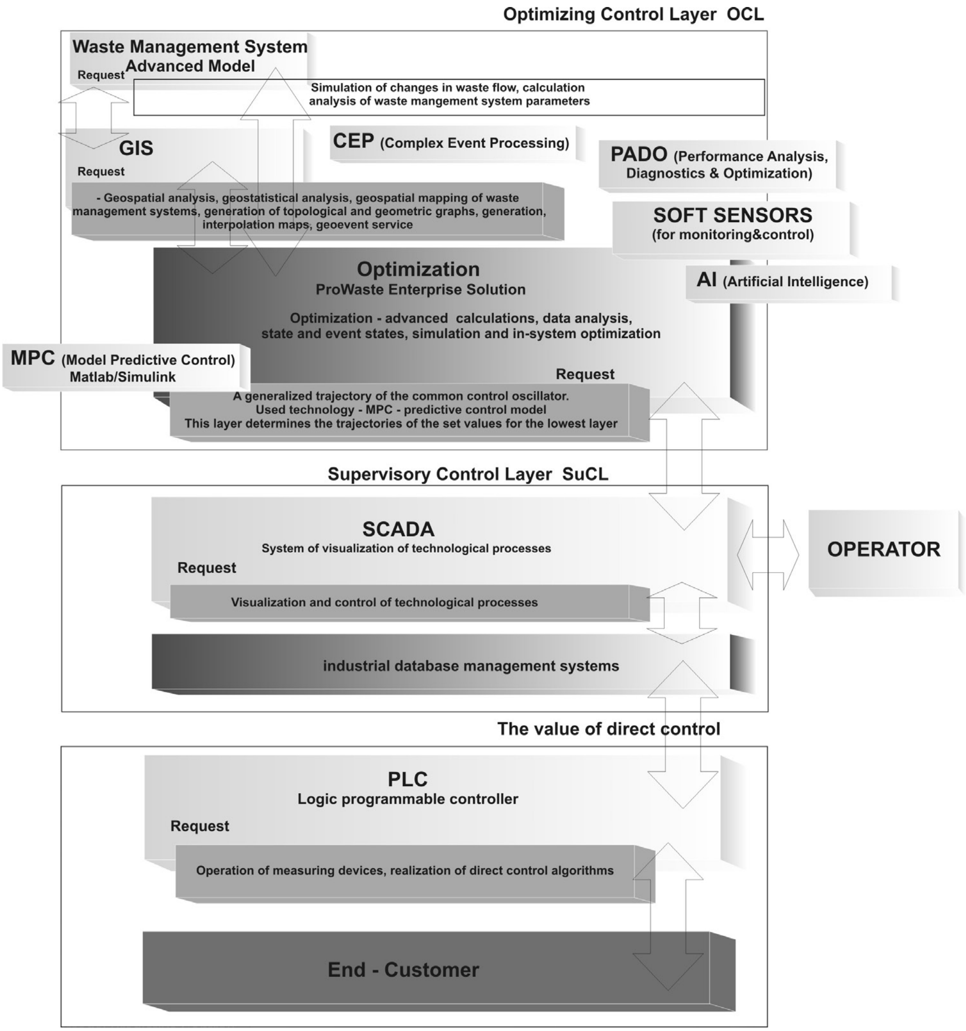

Fig. 2. Architecture/Topology of the System

The Supervisory Control Layer (SuCL) coordinates the individual components of the Waste management structure, evaluates the operational status of the system, and selects the best control trajectory. The observation of the actual control results and its comparison with the forecast allows decision on whether to change the control strategy. Hence, one of the important tasks of this layer is to switch between control strategies [6].

The Optimizing Control Layer (OCL) is responsible for the generation of control trajectories for individual control variables. The MPC – Predictive Control Model is used here. This layer determines the trajectories of the set points for the lowest layer [6, 7, 10].

The Follow Up Control Layer (FCL) is the lowest layer and is responsible for the safety of the processes at the facility, in accordance with trajectories defined in the higher control layer. It has direct access to the controlled object and can implement advanced control strategies developed in higher layers. These tasks implement straight-line algorithms in the form of classical PID algorithms or algorithms written in logic memory of programmable PLC [6, 7, 9].

OCL is divided into three sublayers (slow, medium and fast) corresponding to different dynamics of technological processes in the water supply system and dynamics of interfering inputs. The basic tasks of the slow control sub layer are based on the determination of trajectories of pressures and flows.

The medium control sub layer generates trajectories for output variables controlling the control process, using the MPC model in the full range of the water supply (sewerage) system.

The task of the fast control sublayer is to force the control trajectory defined by the average control sub-set on the object. This sublayer is responsible for meeting the system input control requirements while minimizing power consumption [3, 4].

The operation of the MPC predictive algorithms is based on the knowledge about the future behaviour of the regulated variable in order to determine the value of the control variables. In order to predict the future values of the controlled parameters, the mathematical model of the control object (control object model) uses the previous control signal values and disturbance values (past, present and future) [1- 3, 10]. The basic advantages of predictive control are the following:

- possibility of application for both linear and nonlinear objects / processes,
- the construction of SISO (Single Input Single Output) and MIMO (Multiple Input Multiple Output) control systems,
- consideration of the limitations of process variables,
- incorporation of the internal interaction in the control object by using the object model (the regulator "knows" the object by the control object model),
- incorporation of time delays variable of control objects,
- optimization of the economic indicators related to control.

The MPC algorithm takes into account different types of restrictions:

- limitation of the values of control variables,
- limitation of the increment values of control variable,
- limitation of the output variables,
- limitation of technological variables that are formulated analogously to constraints on output variables.

4. The structure of a virtualized knowledge database on object and process control (MPC)

The expert system supporting the monitoring, control and management of technological processes in water and wastewater management systems is based on the EnviroLab Enterprise Solution Platform component environment. The NVviTT Framework is an advanced technology platform for integrated industrial software (with built-in dedicated modules). The system is scalable in a virtualized modular structure (IFL+CASK+CLOUD). It sets new directions and standards in process simulation, process research and algorithmic control of technological processes, utilizing the latest ICT solutions and advanced predictive and adaptive control models, including laboratory (ACD / Labs, LIMS). The author's innovative solution – the .NavviTT platform, in addition to known solutions, applies real-time knowledge database updated from different, often dispersed sources (process data from SCADA, homo, heterogeneous, structural and non-structural). It uses a number of innovative data processing tools, including validation and statistical analysis.

One of the key elements used in the proposed EnviroLab_Enterprise_Solution is the application of virtual sensors in PLCs to increase the reliability of automation systems by providing rapid response to damage. Virtual sensors are especially useful in situations where it is not possible to measure the process variables (measurement is too expensive; no sensor can be installed in the plant or no suitable measurement method is available).

The main innovations were conducted in the structure of control algorithms, their temporal complexity and the speed of technological process stabilization (followed by optimization). It is crucial to have specialized domain knowledge, dedicated and structured base of knowledge about the expert system, which is logically and physically divided into three independent modules with different functionalities (Fig. 2, 3):

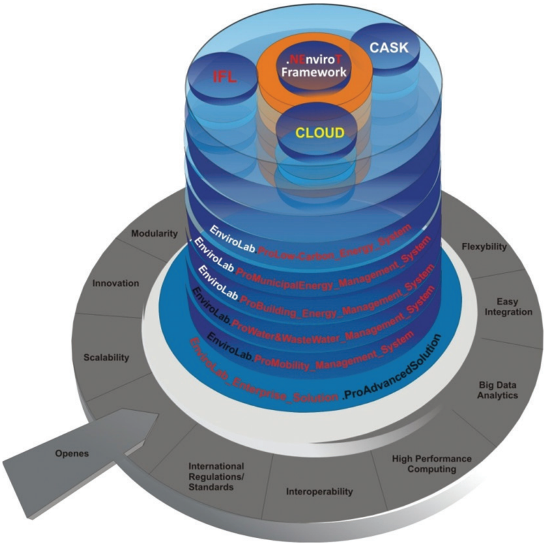

Fig. 3. EnviroLab Enterprise Solution Logical Structure

IFL – Integrated Field Laboratories

The advanced model of virtualized laboratory space supports the process of building and updating the knowledge base of expert system (CASK layer), calibration, validation, testing of MPC/APC control models, event models – by incorporating laboratory test (process, technological, analytical). The IFL environment, through the introduction of the IFL. NEnviroT module is a dedicated tool, including LabResearch_Architect.NEnviroT, which is an expert support system (using LabView, LIMS, ACD / Labs) to conduct research and interpret analysis results. The built-in IFL.NEnviroT advanced research wizard tool allows lab resources to be integrated and a virtual environment to be created – the infrastructure of dispersed labs – by preceding elements of diagnosis, identification, and formulation of a research problem, including the test program required to build a knowledge base for control objects for drivers predictive MPC, adaptive APC, including neural model learning and calibration, validation of object models, events, and real-time updates of knowledge base.

CASK – Cyberinfrastructure, Analytics, Simulation and Knowledge (Expert system in the CASK layer) includes the following functional modules:

- EnviroLab.AdvancedProcessControl (integrated diagnostics and optimization toolkit and advanced APC process control, predictive control of MPC processes)
- EnviroLab.EnvironmentalMonitoring (an advanced HPC solution that simulates pollution propagation and optimizes process parameters to reduce negative environmental impacts).
- EnviroLab.EnterpriseSolutions (open and scalable NET-based platform that utilizes the latest information technology and modular plug-in solutions) dedicated standard. EnviroLab.NEnviroT – provides SDK, API, and many other dedicated / domain tools –which allows applications and standard models to be modified or extended by editing the source code of the class representing the given object, process, etc.

Cloud-GRID – technology

Highly integrated companies are constantly searching for ways to get faster and more efficient data retrieval from industrial installations. One of these is the use of data-driven solutions in the so-called cloud computing, using remote communication through HMI operator interfaces. In the concept of modern industrial networks Industry 4.0 employees and managers have free and remote access to object-level system data. This allows for more efficient resource management, monitoring and control of the machines.

The .NEnviroT platform is based on the environment of intelligent components of process models, events (Complex Event Processing), objects, test models. The knowledge base has crucial significance for the precision of mapping of real processes, objects and events – updated, analysed and validated in real time based on data from various sources (homo/heterogeneous, p/non-structural etc.) computational (e,g. CFD modelling).

The expert system is based on precisely defined models of control objects, where the knowledge base of processes, state spaces, and device performance is built on the basis of expert knowledge and advanced ICT systems. Unlike other solutions, it provides a complete and integrated environment which incorporates advanced IFL, modelling and simulation (CASK) components by moving some of the CLOUD computing solutions.

The adopted technology of system construction provides maximum flexibility (the ability to expand the system with new modules and thematic databases) and scalability (the ability of the designed system to function efficiently with a growing number of users and increasing volumes of data being processed).

5. Conclusions

The rapid development of computer and IT technologies also determines economic development in various sectors of the national economy, including for waste disposal.

Applying advanced computer solutions exploiting intelligent computational techniques enables the passage from the passive position of local government units (JST) in managing the waste disposal to active action, incl. decision making during the problem solving of planning systems associated with the organization of the collection system and the system of the transport of waste and monitoring and comprehensive managing the complex infrastructure of the waste disposal. In order to use ICT systems to increase the reliability of economy systems is waste monitoring in real time, the stabilization of the work of the system and the optimization of logistic and technological processes in the context of the raw material, energy application while simultaneously limiting the influence on all components of the environment (water, air, soil).

This concept of intelligent system of monitoring and managing the management of the municipal waste in metropolises is a response to contemporary challenges in the context of the rapid development of intelligent cities (SMART Cities) in balanced managing the council infrastructure of the management in metropolises, incl. balance of storage, in the context of increasing the effectiveness of using resources.

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