Analysis of RTOS for hardware and software support of environmental monitoring technologies

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Abstract. The article presents an expert analysis of RTOS for hardware and software support of environmental monitoring technologies for hazardous production facilities, including thermal power facilities. The features of the operation of environmental monitoring systems are considered. As the main factors, climatic conditions, mechanical, thermal, chemical, and radiation effects were taken into account. An analysis of the requirements for environmental monitoring systems is carried out, their formalization is given, which fully determines the appearance of the environmental monitoring system. It is shown that the method of comparative analysis allows us to determine the feasible implementation option of RTOS for hardware and software support of environmental monitoring technologies. Expert analysis is presented for Phar Lap ETS, VxWorks and NI Linux Real-Time systems.

1. Introduction
Features of the operation of environmental monitoring systems (EMS) are determined by a number of factors, the main of which are: the operation of the equipment in real time, various environmental influences, the specific composition of the sensors and communications, as well as the complex technology of servicing the equipment (usually in an aggressive environment). These factors affect the structure, software, element base and design of EMS [1-3]. We will consider this effect in more detail and examine the factors that determine the features of operation.

Real-time problem solving in the monitoring network is determined by the need to provide a given system functionality. For the effective functioning of the hardware and software complex (HSC), the information exchange system must have an architecture that provides real-time operation [4]. This means that the structural diagram and software of the EMS must be designed with this requirement in mind. In this case, serious attention should be paid to the adequacy of the algorithms used to solve the problems of processing information and managing the hardware and software complex with real-time requirements. And it essentially depends on the chosen operating system (OS). Next, we will give an expert analysis procedure when choosing a real-time operating system (RTOS) for hardware and software support of environmental monitoring technologies. But at the initial stage, it is necessary to analyze the features of the operation of EMS.
2. Special issues of the EMS operating

The environment, influencing the choice of the element base, the construction of the structure and the creation of the EMS design, is determined by many factors, among which, first of all, climatic conditions, mechanical, thermal, chemical, radiation effects should be taken into account [5].

The main climatic influences are considered to be changes in temperature and relative humidity. The range of changes in operating temperatures for equipment is primarily determined by the climatic zones of the Earth, in which it is possible to use the developed equipment. Since measuring equipment (sensors) can be operated practically in any climatic zones, the range of operating temperatures must take into account the limiting temperature of the medium at various points of the technological object on which the EMS is installed.

For measuring electronic equipment of sensors for various applications, the main mechanical factors are manifested in the form of vibrational impacts and vibration shocks with a frequency of 2 to 7000 Hz at accelerations from fractions of g to 50g; strokes from 65g for pulse durations of several milliseconds (on average 10ms).

The effect of radiation on the microelectronic equipment of measuring devices is similar to its effect on electronic equipment in general. Under the action of radiation, almost all the characteristics of the equipment deteriorate, but at the present time, sets of measuring sensors have already been created that normally function at sufficiently large integral radiation doses - up to 5000 rad.

Storage of on-board equipment should be permissible in warehouses of any type (open, closed, heated and without heating), and transportation should be provided by any type of transport at any distance. The limitations on temperature, vibration, shock and radiation that are available are determined by the type of equipment, application, and the nominal effects are limited to the ranges indicated above.

Environmental factors determine the requirements that the operating conditions of the used elemental base and construction materials must meet [6]. In addition, the technology for creating the design, as well as the design solutions laid down by the developers, should ensure the normal functioning of the equipment in environmental conditions. When creating an EMS structure, technical solutions must be provided that guarantee the operability of the data exchange system during degradation changes in the parameters of the element base under the influence of temperature, humidity, vibration, shock, radiation, etc. [7]. For example, the use of various devices with different degrees of degradation, as well as the use of hardware and software redundancy for switching devices during failures and increasing the information reliability of EMS.

When considering the specifics of the composition of the sensors and the relationships between them for the HSC as a whole, which significantly affects the construction of the EMS, it is first necessary to consider: the number of sensors and their heterogeneity, the number and length of communication lines, the topology of the placement of sensors and communication lines at the technological object, and also the effect of interference on transmitted signals.

At modern monitoring facilities (including thermal power facilities [8-10]), hundreds of sensors are connected as a component of the HSC (usually 50-250 with a maximum number of 1000). Sensors receive and issue information in various forms in a wide range of values of transmitted values with various errors. Summarizing the data of various sensors of monitoring objects for various fields of application, one can imagine the averaged parameters of the entire set of sensors.

It is necessary to briefly dwell on one more characteristic of intelligent sensors reflecting their “intelligence” - the ability to conduct a dialogue with a control system or an operator. In the general case, “intelligent” is understood to mean such sensors that can adapt up to the transmission of information in a natural language. The development of such sensors and their interfaces is currently underway in various countries.

Separate wires, tires and cables are used as communication lines at the facilities. The most promising trunk multiplex buses are fiber optic communication lines (FOCL). The number of communication lines at the facilities is quite large. Often satellite channels can be used for data transmission [11-14]. It is especially relevant for monitoring potentially hazardous technological facilities or in case of emergency at such a facility [15-17].
The specific composition of the sensors and communication lines directly affects all components of the EMS, namely:

- the used elemental base must provide the required speed, accuracy, reliability and operational characteristics of the sensor signals and related parameters;
- the structure of the data exchange system should include: interface units corresponding to sensors and communications; devices for transforming the signal presentation form (analog - code, code - analog, code - code); communication devices with highways, multiplexers, modems, as well as blocks for organizing a dialogue with “smart” sensors and blocks for matching information transfer rates with high-speed capabilities of the control computer when solving EMS tasks [18] (it is necessary to take into account the required types, types and modes of exchange with sensors in the structure, adaptation to any type of sensor);
- EMS software should organize the work of all channels in accordance with the used exchange methods, control algorithms, taking into account the characteristics of the sensors that provide the initial data and process the results of computer calculations;
- the design of the EMS must provide for the necessary switching and installation elements interfaced with the used communication lines (composition, topology, type) and providing the existing requirements for protection against interference; the design must also satisfy the requirement of quick replacement of interface units when changing the used standards on the communication line or the composition of subscribers; design decisions must be invariant to the layout topology of the SEM sensors and the equipment of the EMS itself.

The organization of EMS service most depends on the required reliability of the equipment, the composition of the spare parts, the structure of the control and test (CTE) and control and repair (CRE) equipment, parameters of the resource, storage, transportation, as well as the qualifications of the service personnel [19]. All the factors noted, on the one hand, are determined by the created EMS, and on the other hand, they themselves affect the structure, design, and hardware and software of the EMS. So, the reliability of the system determines the order and frequency of service, but the service itself maintains the specified reliability of the structure of the HSE and the EMS at the appropriate level of the system. Created or existing opportunities for organizing services affect the choice of components, limit the complexity of the architecture being developed and the originality of design solutions.

Let us consider in more detail the factors complicating the maintenance of EMS. The structure of modern EMS is very complex both in functional relationships and in circuit-structural solutions. The use of microprocessors, multi-processing, bus multiplex communications, specialized exchange processors, and the performance of a variety of functions determine the increased complexity of the architecture. All of the above requires the scientific organization of services using modern universal and specialized measuring equipment, as well as continuous training of relevant personnel.

Software, being an essential part of the architecture of modern EMS and affecting the organization of services, requires expanding the fleet of necessary equipment and the range of employees of these services. The use of high-level languages (HLL), developed real-time operating systems, microprogramming determines the existence of resident and cross-tools for debugging work programs, and participating in the maintenance of system programmers and specialists in computational mathematics [20].

To implement highly efficient maintenance that ensures the normal functioning of the EMS for a given service period, design and technological solutions embedded in the data exchange system should provide: the required protection of the equipment from environmental influences; specified reliability; block organization of spare parts; quick replacement of faulty elements; high manufacturability of all inspections and repairs; the required noise immunity of electrical circuits; specified weight and size characteristics when fulfilling industry norms for unification and standardization coefficients; necessary conditions for storage and transportation of equipment.
The main devices, equipment, gadgets and tools used during maintenance are concentrated in the CTE and CRE of exchange systems. This equipment should take into account new solutions for the electronic components base, structure, software and design. This leads to the need to use during inspections and repairs automated equipment based on specialized computers, as well as modern technological equipment. All this also predetermines the participation of various highly qualified specialists.

The considered operating features, their relationship with the used electronic components base, architecture and design of EMS must be taken into account when designing information exchange systems in order to increase the information reliability of environmental monitoring technologies.

3. Analysis of requirements for EMS
For a reasonable analysis of the requirements for modern EMS, it is necessary to clearly represent the full range of their technical characteristics. The whole set of technical characteristics $X$ of the EMS can be represented as follows [19]:

$$X = \{X_a; X_c; X_s; X_e; X_{kn}\},$$

where $X_a$ is a subset of the characteristics of the service; $X_c$ is a subset of the characteristics of structures; $X_s$ is a subset of the software features; $X_e$ is a subset of the characteristics of operating conditions; $X_{kn}$ is a subset of the design characteristics.

Service characteristics $X_a$ include: average service time, probability of servicing an exchange request, average idle time of an exchange channel, probability of channel downtime, probability of finding an exchange system in one of the operating states.

The structure of the EMS is determined by a subset of the $X_c$ characteristics, depending on the type, type and mode of exchange; number of exchange channels; a method for transmitting codes and their type; type of management; control parameters; programmability, adaptability; reliability of operation and actually hardware; bandwidth; number of subscribers; type of interface; electrical characteristics of the input and output signals of the exchange channel; type of used element base.

A subset of $X_s$ includes the type of OS, the programming language, the number of service and standard routines, the amount of memory required to store the software.

Operating conditions (a subset of $X_e$) are determined by the parameters of the environment and the primary power supply network, the time of continuous operation, the technical resource, the parameters of the airflow or microclimate, and the time of readiness for work.

The design characteristics (a subset of $X_{kn}$) are very extensive, but you can limit yourself to the following set of parameters: weight and size characteristics, design type, power consumption, process factors, unification and standardization, precious metal content, maintainability, cost and economic efficiency.

Dozens of the above characteristics fully determine the appearance of EMS, but in practice are rarely used together. It is advisable to include a limited number of parameters in the minimum set of technical characteristics of $X_{\text{min}}$, with sufficient reliability and certainty outlining the appearance of the EMS, for practice:

$$X_{\text{min}} = \{\text{Tobs}; \text{Pstr}; \text{M}c; \text{Cpr}; \text{Pnr}; \text{mA}; \text{Lp}; \text{Xcp}; \text{Ga}; \text{W}; \text{Ca}\},$$

where $\text{Tobs}$ is the average service time, microseconds; $\text{Pstr}$ are probabilities of finding the system in operating states; $\text{M}c$ are types and modes of exchange ($\text{M}t$, $\text{M}b$, $\text{M}p$); $\text{Cpr}$ is the communication bandwidth, kb/s; $\text{Pnr}$ is the probability of normal functioning; $\text{mA}$ is the number of sensors served; $\text{Lp}$ is the programming language; $\text{Xcp}$ are the environmental parameters; $\text{Ga}$ is the mass, kg; $\text{W}$ - power consumption, Bt; $\text{Ca}$ is the cost.

For an approximate assessment of EMS and comparison of various implementations, an even shorter list of technical characteristics is usually used, namely: $\text{M}c$, $\text{Cpr}$, $\text{mA}$, $\text{Ga}$.
4. RTOS for hardware and software support for environmental monitoring technologies

After analyzing the features of operating the EMS and analyzing the requirements, we can proceed to the stage of expert analysis to select the real-time operating system for hardware and software support for environmental monitoring technologies [21-24].

4.1. Phar Lap ETS®
Phar Lap ETS is the optimal real-time solution for devices based on the Intelx86 architecture. ETS provides ease of use and predictable performance, combined with high reliability. ETS is used in multimedia streaming solutions, submicron scanning systems, marine positioning systems and radio frequency identification. ETS is a high-performance real-time microkernel operating system with an optimal 88k operating footprint. Developers can install, configure and start development on ETS within 2-4 hours. The ETS Software Development Kit (SDK) provides a set of tools that integrate seamlessly into the standard Microsoft Visual Studio development environment.

ETS Visual System Builder allows system developers to selectively select kernel components that effectively build the system from the bottom up.

Since ETS was developed as a Win32 API compatible operating system, all standard Windows conventions are supported. This includes the APIs, memory management, mutexes, and semaphores that Windows developers are used to. In addition to productivity, ETS simplifies development with an extensive number of tools designed and optimized to provide comprehensive and detailed information for a software engineer to quickly and accurately solve problems as they arise during development.

The architecture of the ETS core provides complete flexibility in implementation, as it allows system architects to use a monolithic or split core/application implementation. The ability to split the ETS application allows in-place updates to either the kernel or application.

The ETS core is based on a high-speed scheduler that uses both proactive and roundrobin algorithms. ETS supports an unlimited number of threads and provides precise control over applications with 256 levels of assignable priority for the stream. The scheduler ensures that critical thread context switching and transition to higher priority threads occur within 500 nanoseconds in a range of less than 2 microseconds. It is the only real-time operating system that supports a robust subset of the Win32 API and a standard DLL model. These features simplify the migration of applications with Windows-based code and allow you to develop ETS applications in parts with minimal memory. The exact execution of events is crucial in a real-time system. ETS provides complete flexibility for the developer to determine the appropriate timer resolution for his system. The timer interval values can be set between 1 microsecond and 18.2 millisecond.

It is important that ETS provides the developer with a highly functional basis for building systems, including embedded systems, working in real time TCP/IP and USB 1.1 and 2.0. Sophisticated user interfaces and web services are fully supported with the included graphics package and integrated web interface.

Software development using ETS ensures that the needs of the software developer are taken into account. The system provides a comprehensive set of tools that are easily integrated into Microsoft IDE-Visual Studio. These tools enable the software engineer to interactively view the application in real time in order to understand the interaction between the equipment, the ETS core and the ETS application for debugging and analyzing the functioning of the HSC for the environmental monitoring system [24].

4.2. VX Works
VxWorks RTOS is a deterministic, high-performance RTOS that sets the standard for a scalable, future-oriented, secure and reliable operating environment for mission-critical devices and systems that must meet the highest standards. The environmental monitoring system belongs to the type of such systems (see [22, 23]).

The real-time VxWorks system is ideally suited for rigid embedded real-time applications because it is a deterministic, priority-based, preventive RTOS with low latency and minimal jitter. In addition to standard preemption, VxWorks can provide a mode where applications critical to security and time
receive a given number of cycles of the central processing unit (CPU) through various forms of scheduling, as well as time and space sharing. It also provides the flexibility of the functions required for technological processes in various industries [11-14].

Since new functions are added to VxWorks, and the compatibility of functions of different software versions is always quite high, the use of this RTOS in EMS is very promising. Compatibility allows developers to take advantage of the latest VxWorks innovations, allowing them to quickly add new features and updates with minimal re-testing of the entire system, thereby saving time and costs for the project.

The system has ample connectivity and connectivity. Importantly, VxWorks has robust IPv4 and IPv6 stacks that also support time-sensitive networks (TSNs). The system guarantees real-time communication and packet delivery for a limited time or delay on a switched Ethernet network. VxWorks supports innovative industrial applications, including but not limited to OPC Unified Architecture (OPC UA); SocketCAN used in automotive applications; and host, target, and on-the-go (OTG) USB.

There is wide support for multi-core and multiprocessor systems. VxWorks supports 32-bit and 64-bit as well as multi-core processors, including Intel®, Arm®, Power Architecture® and RISC-V. This comprehensive support for multi-core processors allows you to configure RTOS for asymmetric multiprocessing (AMP) and symmetric multiprocessing (SMP) with a processor binding for linked multiplexing (BMP).

Through collaborative development with ecosystem partners, VxWorks has the most extensive list of board support packages in the embedded software industry. Early prototyping, cost savings and flexibility of choice are implemented. Solving the Problem for Rapid Prototyping on Low-Cost Hardware VxWorks offers the open source BSP on GitHub, starting with Raspberry Pi support.

Important for the developer is the reliability and tuning of the system. VxWorks modularity makes it easy to select and adapt capabilities as needed, replacing modules only as needed.

VxWorks’ high level of virtualization provides efficient, near-natural performance in virtualized environments such as the Wind River® Helix™ virtualization platform or other popular hypervisors including QEMU, VMware, and KVM. The Helix platform, which has a built-in certified hypervisor that can save time and effort compared to other hypervisors that are not easy to certify, will also run VxWorks with other operating systems.

VxWorks fault tolerant file system supports the highly reliable Wind River file. There is a system (HRFS) for fault tolerance and recovery operations in the event of a system error and shutdown, as well as FAT-compatible dosFS file system.

4.3. NI Linux Real-Time

National Instruments has developed a Linux-based real-time operating system (RTOS) called NI Linux Real-Time [25].

The level of development is high thanks to many years of research and development, cooperation with the community of open source software developers and the participation of partners. This RTOS is available on some NI hardware, which will be described below. NI Linux Real-Time is fully supported by the NI LabVIEW development environment with the LabVIEW real-time module.

Linux has long been used in embedded systems, largely because it is a free, open source system, and is also developed and supported by the development community [26]. With early use, firmware developers came to the conclusion that Linux cannot be an RTOS, and over time have developed many hybrid approaches that combine Linux with a dedicated RTOS for use in embedded applications.

As the use of Linux in embedded system development has become more mature, developers have also added features to improve the determinism of the Linux kernel itself. More recently, the PREEMPT_RT patch set, which is the result of efforts to improve the Linux kernel, is increasingly becoming the generally accepted approach to achieving real-time, real-time results with Linux.

Let’s dwell on the benefits of NI Linux in real time. Historically, real-time performance has been achieved through usability. It is important that for NI Linux Real-Time, the advantages and usability
that Linux offers are also transferred to the OS itself, since most of the advantages arise from the Linux kernel, which is not violated. Thus, NI Linux Real-Time offers attractive real-time performance along with the previously highlighted RTOS, but without sacrificing usability. An example of the enhanced usability provided by RTOS is the proven and stable network stack, borrowed from universal Linux. Thanks to an improved network stack, real-time targets that support this RTOS can support real network interface cards with two DHCP servers (NICs) and do not require a reboot to apply changes in network settings or time, and also offer wider support for communication protocols such like IPv6 and SNMP. Another compelling example is the display support for local HMIs that NI Linux Real-Time offers in the new CompactRIO performance controller.

In addition, since Linux is much more widespread than even the most popular specialized RTOS on the market, this RTOS offers a much richer ecosystem and toolkit, as well as a significant base of experienced users who can use the potential of RTOS. When using the real-time mode, which is supported by NI Linux Real-Time OS, we have great freedom to complement the functionality of our solution with elements of the Linux ecosystem. You can also take advantage of the extensive base of experienced Linux users. Note that NI Linux Real-Time empowers users. From the simpler addition of third-party peripheral hardware support, such as custom sensors, to the much simpler C / C ++ code integration.

In addition to usability and the ecosystem, unlike many dedicated RTOS, NI Linux Real-Time is a true dual-mode OS. As a dual-mode OS, NI Linux Real-Time offers significantly more stable operation. In the event of an application failure, the system continues to work and can recover from an application failure without significant loss. NI Linux Real-Time also supports true multitasking, allowing you to run multiple programs in parallel. For example, you can run the database directly on real-time objects with the LabVIEW Real-Time application.

Finally, relying on Linux, this RTOS offers a significantly improved ability to manage user accounts and user file system permissions. User activity can be more easily recorded on embedded devices that support NI Linux Real-Time. In addition, security features such as VPNs and firewalls can be implemented, eliminating the need for additional external equipment solely to increase network security.

NI Linux Real-Time delivers real-time performance along with dedicated RTOSs available for current-generation CompactRIO targets. NI Linux Real-Time Goal Jitter is of the same order of magnitude as jitter in modern NI real-time systems. For real-world control and streaming applications, NI Linux's real-time CompactRIO offers a significant increase in performance because control and streaming transmissions operate at a higher cycle rate with a lower processor load.

5. Conclusion

Thus, when choosing an RTOS for EMS, one should clearly represent the range of design work performed at the appropriate stages and levels using certain EMS design methods and specialized sensors.

The method of comparative analysis allows us to determine the feasible implementation option of RTOS, but has the main disadvantages: in most cases, in practice, the decision is made on the basis of a combination of quality indicators that take into account the technical characteristics of the operating system and similar class parameters of such systems, and on specific characteristics. This is usually done in a non-automated way, which reduces the development efficiency. Since at the same time, at each step of decision-making on a certain parameter, a group of RTOS options is selected for further consideration, there is the possibility of losing an implementation option of RTOS that is best for evaluating the next stages of analysis. This method does not allow you to create new technical solutions, as it is focused on evaluating a heuristically specified set of competing options. The noted drawback of comparative analysis is excluded when used for the design of synthesis methods [27-30].

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