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INCREASE OF THE DEPENDABILITY AND ADAPTABILITY OF CRITICAL INFRASTRUCTURE' IIOT SYSTEMS

One of the trends in modern solutions for emergency situations and activities in hazardous environments is the implementation of network access to critical infrastructure system resources. As a result, the technology of remote management has developed, including Industrial Internet of Things (IIoT) systems. Their implementation aims to enable data collection, exchange, and analysis in a network of interconnected sensors, devices, and industrial software. However, such networked systems still require a classical approach to direct device control through a visual and tactile Human-Machine Interface (HMI). Therefore, the research on critical infrastructure systems prominently addresses the creation of software and hardware components suitable for building such systems, considering both technological and security requirements. An evident requirement is to ensure the dependability, flexibility, and ability to modify their architecture while performing functional tasks in a volatile and highly dynamic production environment.

The prerequisites for this research are the current advancements in the development of communication systems, storage devices, and peripheral devices for EmSYS and IIoT systems. In particular, the ideas regarding the implementation of hybrid forms of solid-state memory in embedded components of IIoT systems, adapted to high dynamics of information exchange, are relevant.

A limiting factor for the effective integration of memory on the control board (SRAM, DRAM, SPIFlash, and external SD card memory) and all types of memory of the WiFi module is the absence of software tools for working with variable memory in terms of type and loading methods. This problem is further exacerbated by the hierarchical and group approaches to IIoT management. As a result, there is a need to enhance the flexibility and efficiency of memory utilization in multilevel IIoT systems.

The research task involved the creation of software tools for working with files and data in the hybridized memory of embedded components in the IIoT system, loading programs into such memory using the WiFi channel, and the development of a library adapted to this architecture to create efficient human-machine interfaces.

Regarding the implementation of hybridized memory in IIoT systems, we started from the premise that the development of electrically erasable programmable read-only memory (EEPROM) semiconductive technology provided an increase in its information capacity to a level that satisfies the needs of long-term data storage in ultra-mobile personal computers (UMPCs). However, the expectations associated with the development of this technology for eliminating the main drawback of EEPROM, namely physical wear, turned out to be futile. Furthermore, as the information capacity of flash memory increases, the endurance to erase/write cycles at the level of individual cells decreases. Available data indicate that this parameter also depends on the type of NAND cells [1]. The problem of low resistance to physical wear can be mitigated several times by dynamically and statically balancing the load across the entire memory array.

However, in the conventional implementation of solid-state drives, an acceptable level of reliability has only been achieved for UMPC-class devices.

A radically different approach to minimizing physical wear is the use of hybrid architectures, such as combining SSD Flash with a ferroelectric random-access memory (FRAM) memory chip manufactured using magneto-electric technology, which has been proposed under the name Chameleon [2]. In this architecture, the metadata of the SSD flash memory is stored in a small FRAM, as they are the objects of intensive random write operations, while the bulk data is stored in the flash memory. In addition to minimizing SSD Flash wear, it is claimed that the Chameleon architecture improves UMPC performance by more than 20%.

Unfortunately, hybridization combining SSD Flash/FRAM is not feasible for most embedded systems due to the significant cost of SSD drives and their excess information capacity for IIoT devices. More optimal options are split-systems such as eMMC/FRAM, SD-card/FRAM, or SPIFlash/FRAM. The relevance of research related to them lies in establishing forms of software component implementations for hybrid architectures when operating in embedded systems. Our goal was to obtain file system utilities that, together with the corresponding hardware modifications of solid-state drives, would ensure the integrity, preservation, and operational access to files, considering high information dynamics in normal and emergency operation modes of IIoT systems.

Remote access to the energy-independent memory of IIoT devices with split-system architectures like SD-card/FRAM and SPIFlash/FRAM is proposed to be implemented using the HTTP protocol since it allows standardizing the approaches to accessing hybrid drives and managing the IIoT system according to its utility purpose. The use of WebDAV extensions allows not only for collaborative editing and management of collections stored on the server but also minimizes data security threats. The interaction of the access agent with file repositories is modified according to a specially developed model.

The analysis of the subject area, methods, and tools for remote file loading into IIoT system parks with combined program memory has demonstrated the following: 1) the relevance of implementing a software loading application for system device software in the form of a browser utility using client-server architecture; 2) the importance and possibility of preserving their basic control when connected to a computer network; 3) the necessity of providing remote management services; 4) the ability to provide scalability for wireless execution through the software configuration of WiFi modules in "station" mode, while the WiFi resource of UMPC or other mobile devices operates in "access point" mode. The current research results were only tested on Espressif Systems' ESP12F and ESP32-WROOM32UE modules.

The practical implementation of the proposed solutions is rational in the form of the HTTP-FileLoader browser utility and HTTP server software. They are intended to enhance the utilization of embedded and external memory in IIoT system parks, perform system settings, and set technological parameters in OTA mode, as well as improve the efficiency of remote management of technological processes as a whole. However, it should be noted that the current obstacle for the application of such proposals is the absence of optimal file systems for working with energy-independent hybrid memory components of IIoT systems. Specifically, additional adaptation of FAT32 and SPIFS is

required for these applications. The prospects of more specialized file systems like LittleFS and TinyFS for IoT systems are also being studied.

Creating IIoT systems based on WiFi modules and hybrid memory imposes additional constraints on the components and interface extensions of the software intended for personnel interaction with system components. In general, they should consider the specific environmental and operator equipment factors in mobile application scenarios. However, the features of the proposed human-machine interaction hardware support necessitate the creation of an adapted library for HMI components of such purpose. Its development takes into account the need to address the following factors:

- fast display of a significant number of HMI window widgets without delays or the appearance of static or dynamic visual artifacts;
- ensuring the applicability and scalability of the HMI image, both for windows and widgets and events;
- minimizing the SRAM and EEPROM memory requirements proportionally to the set of HMI window widgets, easy integration of graphical component code into the overall code of the target product;
- high portability and compatibility with embedded system hardware or software platforms, as well as ease of updating;
- reliability and resilience to system failures;
- ease of use and intuitive perception;
- providing aesthetic appeal;
- convenience of support and compliance with standards.

The analysis of possible solutions to the problem has shown the relevance of perceiving a GUI library not only as the ultimate goal of design but as a tool for implementing modern HMI application design methods. This approach served as the basis for synthesizing a model of the software development process for HMI extensions in embedded systems. With the dominant role of GUI components, the profitability of embedded software development can be increased by separating the HMI design stage into a separate process involving specialized design and visualization tools for the HMI model. Using this model allows editing, verification, and display of the HMI structure during the HMI model creation stage and its derived components. These stages are based on processes involving obtaining a list of variables and binding model objects to both variables and system events. The results of creating the model include integration or loading of the HMI image into the graphical extension of embedded systems.

The project model focuses on the extensive use of LCD block commands, a balanced set of widgets, the structuring of their attributes and states, the conveyor formation of video frames, and the description of the HMI project image in XUL or XAML markup format. It also includes hardware optimization, such as minimizing the EEPROM and SRAM requirements as well as the CPU load of the WiFi module. Specifically, the basic set of widgets is limited to 8 units with the possibility of optional expansion, and the list of their attributes does not exceed 10. In comparison to similar libraries, the list of events requiring processing has been reduced.

Thus, models, methods, and technologies for improving the reliability and adaptability of critical infrastructure systems created based on the concept of Industrial Internet of Things have been analyzed. It has been identified as prospective to enhance the reliability of solid-state memory devices for EmSYS and IIoT systems in split systems with hybrid

SD-card/FRAM and SPIFlash/FRAM architectures. Effective use of hybrid SSDs requires the development of appropriate file system implementations to handle information processes. Optimal forms of implementation and architectural requirements for wireless program and data loading utilities in IIoT systems have been determined. The GUI library implementation for HMI based on WiFi modules has been optimized, taking into account the specific implementation of EmSYS and IIoT systems by forming a weighted set of visual components, aligning functionality with the MVC pattern, enabling DMA mode for streaming video data, and intensifying LCD block commands in video frame update processes.

We expect that the implementation of the obtained results will improve the characteristics of software-hardware complexes of critical infrastructure systems through effective support for remote resource access, prompt system and technological adjustments, and the enhancement of HMI tool development.

Abstract

The paper is focused on the problem of increase of the dependability and adaptability of IIoT systems in critical infrastructure. The problem is considered in the context of implementing hybrid forms of solid-state memory in embedded components of IIoT systems, adapted to high dynamics of information exchange. Restraining factors for efficient operation with variable memory in such systems have been analyzed. The optimality of split systems such as eMMC/FRAM, SD-card/FRAM, or SPIFlash/FRAM has been justified. A method for remote access to the non-volatile memory of IIoT devices with hybrid architecture in such split systems has been proposed. A model of interaction between the access agent and file repositories has been developed, and prototypes of file system utilities for working with hybrid hardware modifications of solid-state drives have been obtained. A solution has been proposed for developing software interface extensions intended for personnel interaction with components of the IIoT system based on the software development process model for embedded systems' HMI extensions. An optimized GUI library implementation for HMI based on WiFi modules, taking into account the specific implementation of EmSYS and IIoT systems, has been developed.

List of references

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