International Journal of Electrical and Computer Engineering (IJECE)
Vol. 13, No. 2, April 2023, pp. 1338~1345
ISSN: 2088-8708, DOI: 10.11591/ijece.v13i2.pp1338-1345

Designing smart pulse flow meters using diversion analysis

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Article Info

Article history:

Received Apr 5, 2022
Revised Aug 25, 2022
Accepted Oct 1, 2022

Keywords:

Diversion analysis
Flow meter
Home automation system
Internet of things
Smart home

ABSTRACT

The operation of modern housing infrastructure is characterized by a constant increase in the cost of the limited resources used. This necessitates the priority implementation in the concept of a smart home of elements aimed at resource saving and their rational management. The study provides an overview of the implementation architectures of the internet of things (IoT) concept in the construction of home automation systems and the requirements they impose on the implementation of smart primary meters of controlled physical quantities. Based on a diversion analysis, a promising smart water meter was developed. The prototype is ergonomic and has a structural form factor convenient for further integration. The designed model of the electronic module of the water flow monitoring system implements, in addition to typical tasks, additional functionality: transfer of recorded indicators and technical information to the cloud storage, warning the user about an emergency situation, accumulation of current data in non-volatile memory. It is possible to use the accumulated statistics for training the predictive analysis module. The proposed architecture option will allow creating energy-efficient elements of home automation systems in the future.

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1. INTRODUCTION

In the context of digital transformation, such trends as smart city, smart home, smart factory, and smart education. are gaining more and more development. The smart environment is a new technological niche with high growth potential. However, at the moment, less than 15% of the population of the world's largest metropolitan areas uses smart solutions for home automation [1].

The operation of modern housing infrastructure is characterized by a constant increase in the cost of the resources used (electricity, heating, and water). The global demand for water is growing; its available volumes are decreasing. This necessitates the priority implementation of elements aimed at water saving in the concept of a smart home [2].

The implementation of the concept of smart home is based on smart technologies, which are a set of integrated technologies that can automatically respond to changing environmental conditions and ensure user satisfaction [3]–[5]. These technologies are used to improve the quality of life, eliminating negative environmental impacts [6]. One of the effective methods for taking into account negative phenomena in systems of various classes at the early stages of design is diversion (inverse) analysis [7], [8]. The method can also be applied to control the consumption of natural resources in the field of designing advanced smart pulse flow meters. The study will focus on the application of diversion analysis.

At the moment, in a typical non-modern household, devices are used, the indicators of which are processed manually. These devices have limited real-time control over resource consumption, so effective consumption management can be difficult. A high concentration of outdated households is observed in Russia, which creates an urgent problem of large-scale renovation of home resource metering devices, in particular, regarding the issue of water consumption [9]. Now the Russian market of home automation systems is moving from local digitalization to the implementation of integrated smart home solutions. In this regard, the aim of the study is to develop smart pulse flow meters using diversion analysis, which are distinguished by reliability, affordability, and ease of use. In our case, the object of research is a water flow monitoring system, the subject is the design of smart pulse flow meters.

The problem of creating a smart water meter module is currently receiving a lot of attention. However, there are still questions about the additional functionality of this class of devices. As part of the study, a new design of the module, new functionality that is not available in ready-made solutions, was proposed. The proposed new solution differs from the known analogues by the presence of a display located directly on the device, which makes it possible to see the current readings, without the need to use a computer. The developed device also has a non-volatile memory chip for storing data in case of a power failure. The device is powered from the mains, not from the battery, since the batteries have a short life. To connect a computer system, a wired connection is used, which is more noise-immune than wireless.

2. LITERATURE REVIEW

Modern implemented systems for monitoring and accounting for resource consumption should not only record the readings of individual measured values but also carry out their intelligent processing and predictive analytics [10]–[12]. They are characterized by the use of 4G-5G technologies, semantic networks, open data, cloud computing, digital twins, single integrated digital data exchange platforms [13]–[18]. The implementation of modern smart solutions is based on the concept of the internet of things (IoT). The classification of basic IoT architectures is shown in Figure 1.

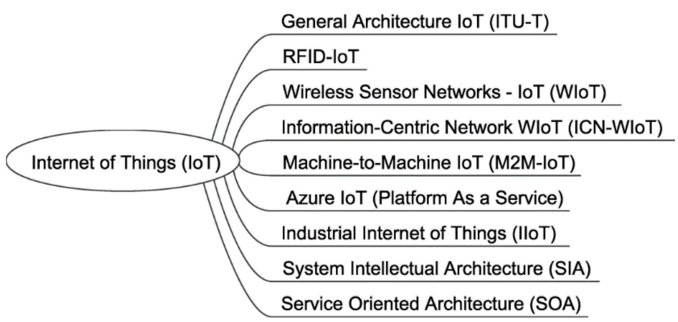

Figure 1. Classification of basic IoT architectures

At the beginning of development, the RFID-IoT architecture prevailed, unambiguously identifying automation objects connected through RFID radio frequency identification technology [19]–[21]. New IoT functionality has become achievable with the introduction of architectures based on wireless sensor networks (WSNs) [17], [22]. The subsequent development of the IoT concept was characterized by the emergence of a multi-layered intelligence of the IoT (artificial intelligence of things (AIoT)) and the formation of an intelligent cyber-physical environment [23]. If the first versions of IoT systems used cloud computing technologies, implementing support for machine-to-machine interaction (M2M), then modern implementations actively use intelligent sensors and predictive analytics [24]. Recently, service-oriented architecture (SOA) and system intellectual architecture (SIA) have been widely used to implement IoT solutions.

The use of SOA for IoT as a technology for integrating heterogeneous systems or devices has made it possible to move on to the creation of multilayer SOA architectures [23]. Another popular solution is the implementation of the multilayer intelligence of the Internet of Things, which is understood as a multilayer architecture of a smart object based on IoT-SIA [25]. A generalized block diagram of this architecture is shown in Figure 2.

The IoT architecture model, SIA, shown in Figure 2 is suitable for most scenarios where a set of Internet-enabled devices interact with the environment. The SIA architectural model is widely used in IoT application ecosystems. One of the main problems in the development of SIA is the relatively low rate of distribution of intelligent modules for the initial registration of information. To reduce the load in modern solutions, part of the data pre-processing is transferred directly to smart recorders. A deterrent to the implementation of the IoT-SIA architecture is also the lack of a single standard for the components of the SIA architecture and the data exchange protocols between them. By and large, IoT devices, such as smart water meters, gas meters, and electricity meters, are architecturally almost identical by 90–95%. Therefore, when developing, it is advisable to create not just a separate element of measurements, but a complex hardware and software platform for the intellectualization of measurements. As an example, consider approaches to the development of intelligent water flow monitoring systems [10], [26], [27]. The classification of the main flow meters is shown in Figure 3.

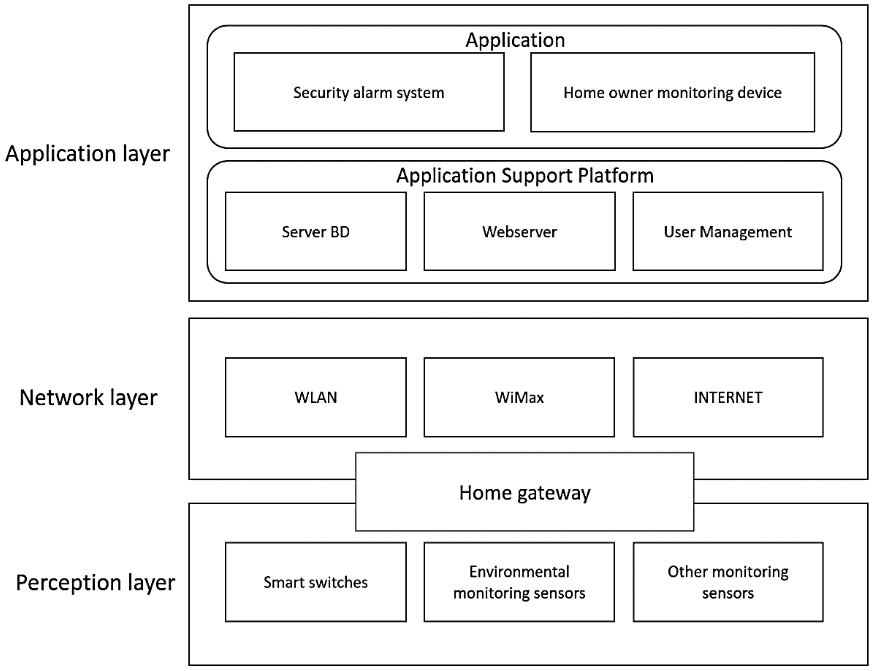

Figure 2. SIA model of smart home architecture [23], [25]

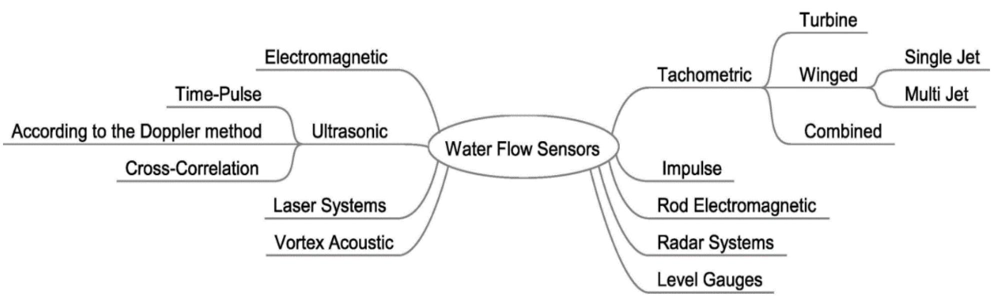

Figure 3. Classification of the main water flow meters

Modern approaches to the design of smart flow meters should be based on a modular principle, when the desired solution is synthesized from a set of typical blocks (intelligent properties (IP)). Smart flow meters must have an efficient technology for the primary registration of the measured physical quantity, energy-efficient data transmission interfaces, and built-in analytical functions. Analyzing the Russian market of smart flow meters, one can distinguish the following similar main characteristics as shown in Table 1.

A modern smart recorder must transmit pre-processed data to resource providers (implement smart metering functions in IoT). Smart IoT recorders must respond to configured events in real time. They must notify the customer via mobile email when controlled events occur. One of the bottlenecks of smart recorders is their volatility, so they must operate without the need to replace the battery for many years [28]. Therefore, an actual engineering solution is to create such a water consumption monitoring system for daily use, which would be distinguished by low cost, simplicity, and reliability of operation.

Table 1. Common water flow monitoring systems in the Russian market

Name	Mount type	Serial interface	Additional features	Type of power supply
SAURES Wi-Fi (www.saures.ru)	Remote module	Wi-Fi	None	Battery
ELEHANT SVD-15 (https://elehant.ru)	The module is built into the meter body	Bluetooth	Remote display	Battery
SVK 15-3-7 with Strizh radio module (http://strijug.ru/)	The module is built into the meter body	XNB	None	Battery
WAVIoTAQUA (https://waviot.ru)	The module is built into the meter body	NB-Fi	None	Battery
Smart Meter (https://ru.rd-technoton.com/)	The module is built into the meter body	NB-IoT, Bluetooth MQTT	Built-in analytics and leak detector	Battery
NB-IoT water smart (https://ru.rd-technoton.com/)	The module is built into the meter body IoTBurger.	GSM MQTT	Embedded analytics	Battery

3. METHOD

Creating an effective smart system for monitoring water consumption is a complex multi-criteria task. To solve it, it is advisable to use one of the methods of the theory of solving inventive problems-diversion analysis [7], [29], [30]. In the considered case, the object of research is a water flow monitoring system, the subject is the design of smart pulse flow meters. A generalized block diagram of a typical smart flow meter includes: microcontroller; module XNB; battery powered; housing integrated in the water meter. Using the method of diversion analysis, one can identify the main negative aspects of the introduction of smart flow meters by inverting the problem being solved. The task of designing pulse flow meters is inverted using a mind map that will reflect their typical negative design features as shown in Figure 4.

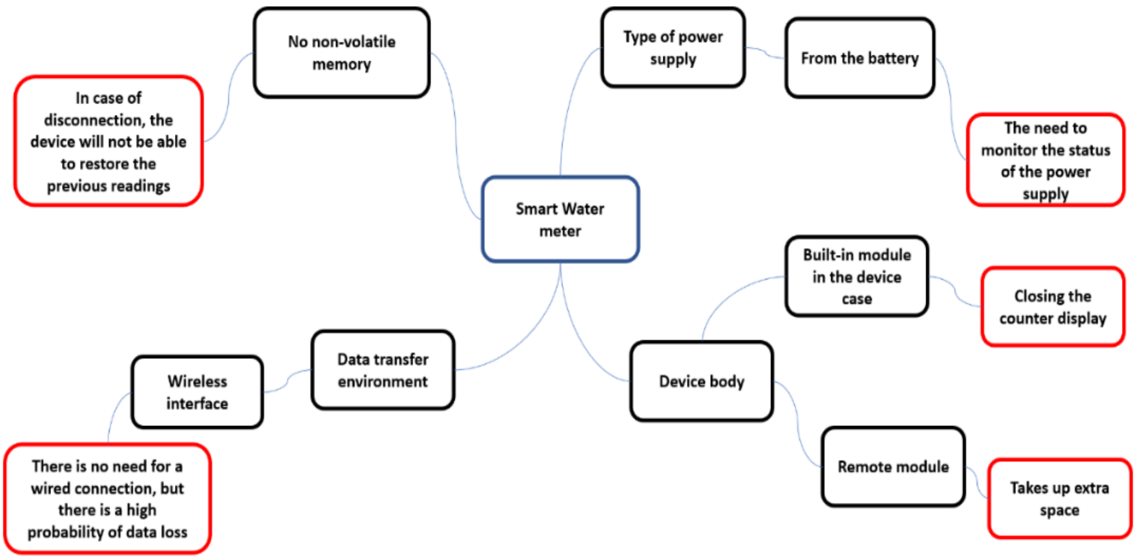

Figure 4. Negative design features of flow meters

Let us formulate diversion hypotheses based on the analysis of the generalized block diagram of a typical smart flow meter and its characteristics, systematized according to the literature review. This analysis allows identifying a number of potential device vulnerabilities. Among them are the following: the use of battery power for a smart flow meter requires the consumer to replace the battery in a timely manner, which is inconvenient to maintain the device; connecting it to the power supply network makes the flow meter dependent on the state of the power supply network; the use of wired data transfer interfaces complicates the installation of the flow meter in hard-to-reach places; the use of wireless data transmission channels makes it sensitive to interference; the use of a built-in housing directly into the design of the flow meter without light indication makes it difficult to use the device without connecting to a computer. All this forms the subject contradictions of design. The mind map was developed according to the principle of how to degrade the properties of the developed flow meter.

Having formulated diversion hypotheses, one can proceed to the definition of diversion resources, which is necessary for the spontaneous realization of the identified undesirable effect. After, verification and validation of the mechanisms of their action are carried out within the framework of the accepted diversion hypothesis. Consider the application of the described method in the development of smart pulse flow meters. The following section describes the use of inverse analysis to create a new functionality of the smart water meter module. The negative effects resulting from the inverse analysis will be used as new features in the device under development.

4. RESULTS AND DISCUSSION

Based on the negative effects identified above in flow meters as shown in Figure 5, one can conclude that the device under development should have the following design features: i) The data interface must be wired, thereby leveling the loss of data; ii) In the system being developed, it is necessary to use a non-volatile memory chip in case of an emergency power outage of the device; iii) The type of power supply should be selected from the mains, with redundancy from the battery cell; and iv) The device must be designed so as not to take up additional space, but at the same time not obscure the indication of the flow meter itself.

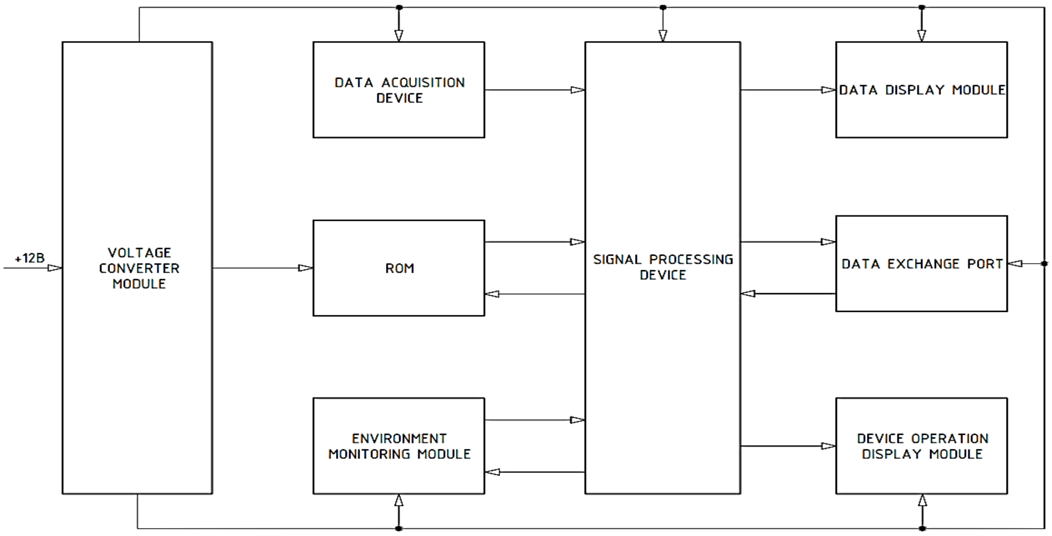

Figure 5. Structural diagram of the data processing module of the flow meter

The block diagram of the generated solution that satisfies the specified requirements is shown in Figure 5. The process description of the operation of the water flow meter is as follows. Upon consumption of a given volume of water, the water meter generates a pulse, which is fed to the input of the signal processing device. The signal processing unit processes the impulse and saves it to an external non-volatile memory, in case the device is turned off from the power supply. The processed information is sent by the signal processing device to the data exchange port. The water flow monitoring system must be wired to the data receiver. In the device under development, an environmental monitoring module is provided, which is a climate sensor that measures temperature and humidity. In the event of a leak, the sensor sends a signal to the input of the signal processing device. In turn, the signal processing unit forwards this signal to the communication port. To improve the ergonomics of the device, a data display module has been added, which makes it possible to access the meter indicators without turning off the device.

The solution to the problem of ergonomics of the device is the development of a printed circuit board in the form of a round plate; this design solution makes it possible to mount the device on top of the water meter housing. Placing a light indication in the center of the printed circuit board makes it possible to observe the readings without removing or turning off the device. The result of the implementation of the block diagram was the development of the design of the electronic module, shown in Figure 6. Figures 6 (a) to (i) show the 3D model of the electronic module of the water flow monitoring system, which consists of read only memory (ROM), voltage converter module, additional data exchange port, button, DC input, water meter input, shift register, data exchange port, and display.

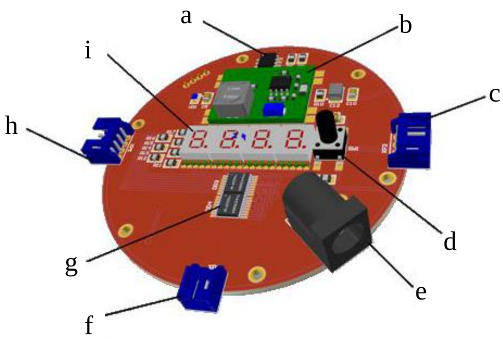

Figure 6. 3D model of the electronic module of the water flow monitoring system: (a) ROM, (b) voltage converter module, (c) additional data exchange port, (d) button, (e) DC input, (f) water meter input, (g) shift register, (h) data exchange port, and (i) display

The proposed solution is rational and ergonomic, uses Wi-Fi technology (2.4 GHz) for data transmission, 5 V power supply, has a round form factor, which makes it structurally convenient for subsequent integration with a water meter into a single design. Placing the organic light-emitting diode (OLED) light indication in the center makes it possible to take readings directly without additional steps. This solution implements, apart from the typical tasks, additional functionality that is not provided by other considered similar devices in Table 1. The transfer of recorded indicators and technical information to the cloud storage provides the necessary basis for further training of the predictive analysis module. For example, in the event of a pipe leak, the system will warn the user about an emergency situation. Non-volatile memory makes it possible, instead of constantly transferring information to the server in case of a change in readings, to do it according to a planned schedule. The use of a wired interface makes it possible to use the device in places remote from the base station with a difficult interference environment.

Let us analyze the flow meter device developed using the diversion method. The proposed device uses Wi-Fi; this solution has its advantages and disadvantages compared to analogs. Wi-Fi technology has a small network coverage area, due to the high signal frequency (2.4 GHz). This feature is leveled by the high prevalence of Wi-Fi routers. When developing this device, a client-server architecture was used, that is, when using the device outside residential premises, for example, in industrial or basement, it is enough to install one Wi-Fi router to connect many devices. Many analogs use narrowband-internet of things (NB-IoT) technology-this technology is based on the telephony standard, so such a device can be used where there is cellular coverage. However, NB-IOT has a drawback-the lack of communication in rooms with poor signal penetration, so this solution is difficult to use in basements. When using the low power wide area network (LPWAN) protocol, due to the lower frequency (868 MHz) compared to other technologies, the signal can pass through many obstacles, but special base stations are required to ensure the network coverage, so the use of such a device is limited by the availability of the necessary infrastructure.

To record readings in direct contact with the device, the presented solution uses a small OLED screen, which makes it possible to comfortably observe the readings in low light conditions. Devices in the market use analog indication without backlight. An external AC/DC 5 V power adapter is used to power the water flow monitoring system, which eliminates the problem of device maintenance. Analogs use a battery with a supply voltage in the range of 3.3 to 3.6V.

The devices that are offered in the market are already built into the body of the meter itself and represent a single monolith, that is, if a consumer wants a smart meter for him/herself, then he/she needs to completely replace the fixing devices with new ones that support this function. To solve this problem, the water flow monitoring system board was designed in the form of a round plate, for subsequent installation in the housing, i.e. the solution is modular and interchangeable. For ease of fastening, the case is fixed on top of the user's meter case. With this design of the device, the replacement of devices is not required.

Most smart meters use wireless data transmission, but not everywhere there is a base station or a stable mobile connection, so the developed solution uses a wired connection. To control the leakage of pipes in the design of the device there is a humidity sensor, this function is absent from analogues. If you want to know the current reading, similar solutions offer only the connection using a computer, in this development it is possible to interact both directly with the device using the display, and with the computer. The result of the research was the creation of a new design of the smart meter module, with functionality that is absent in the devices on the market.

5. CONCLUSION

The study proposes an original design solution for remote data collection from water flow recorders, obtained using an inverse approach to the design of complex systems. The developed design of the electronic module of the water flow monitoring system implements, apart from the typical tasks, additional functionality, which is not provided by other similar devices under consideration: the transfer of the registered indicators and technical information to the cloud storage provides the necessary basis for further training of the predictive analysis module; non-volatile memory makes it possible not to constantly transfer information to the server in case of a change in readings, but to do it according to a planned schedule; the use of a wired interface makes it possible to use the device in places remote from the base station with a difficult interference environment. The diversion analysis borrowed in the design made it possible to identify obvious and hidden causes of possible failures, vulnerabilities, and risks in the early stages of development. The proposed architecture option will allow creating energy-efficient elements of home automation systems (smart meters for gas, electricity, heat and other resources) in the future.

ACKNOWLEDGEMENTS

Some project results were achieved with the financial support from the Ministry of Science and Higher Education under Project No. 0705-2020-0041 "Fundamental Research of Digital Transformation Methods for Component Base of Micro and Nano systems".

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