E3S Web of Conferences **401**, 01012 (2023) https://doi.org/10.1051/e3sconf/202340101012
CONMECHYDRO - 2023

Intelligent device for measuring water level in irrigation channels of constant section

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Abstract. The article discusses the problems of online monitoring of water metering in the irrigation systems of Central Asia, in particular the Republic of Uzbekistan, and identifies existing problems. The development of intelligent level measurement devices is aimed at solving these problems. A technique has been created for developing an intelligent level measurement device capable of operating stably even under various disturbing influences, considering abrupt climate changes. Based on this method, an intelligent device has been developed that allows online measurement of the water flow and its amount flowing in the channel based on measuring the water level in channels with a constant cross-sectional area. The device has the function of automatic selection of alternative networks for the exchange of information, such as GSM or Lora, depending on the conditions of information transmission over long distances. The device also includes the function of autonomous charging using solar energy in places with no power supply. The industrial sample of the device was tested and certified in laboratory and field conditions and at the National Certification Center of the Republic of Uzbekistan, and permission was obtained for its mass production. Because local manufacturers produce this device, it has advantages over its imported counterpart in terms of low cost, the availability of customization options, and easy adaptation to difficult conditions. In exchange for applying a smart filtering algorithm, the stabilization of received signals is improved by 74.2% due to intelligent filtering algorithms in a smart device. The reliability of information decreased by 8.2% in total. This result is less than the 9.5% target for information reliability.

1 Introduction

The rational use of water resources in the regions has become an increasingly urgent task in recent decades. An article by the French Academy of Sciences titled "Regional Waters" suggests possible measures to identify the possibility of serious global crises due to water-related problems and prevent such crises. According to the article, factors such as climate change, the growth of the world's population, the deterioration of the quality of drinking water, and the increase in the number of megacities in developing countries (with more than

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ten million inhabitants) are potential risk factors for the reserve of water resources [1]. In studies conducted by Swedish scientists, it was found that groundwater also affects the pollution of surface and coastal waters [2]. Satisfying human needs with limited water resources requires optimization. In this case, it is appropriate to refer to the paradigms of the concept of water policy [3]. The implementation of water policy will require a full study of existing processes and obtaining sufficient information about their parameters. The expansion of cultivated areas in countries such as Central Asia, whose main production is related to the agro-industry, leads to increased technological solutions for irrigation monitoring. In addition, while the central circulating irrigation systems used in these fields have made farmers' daily work easier in recent years, monitoring these systems and reporting problems in their operation has become a key aspect during the growing season. Therefore, various monitoring solutions are being developed in the fields of precision agriculture and information and communication technologies (ICT). Nevertheless, for these solutions to be user-friendly, it must be considered that their potential users should be low-cost solutions [4]. About 85% of the world's fresh water is used for irrigation. Therefore, existing irrigation procedures should be updated or replaced with advanced intelligent systems using ML, IoT (Internet of Things), and wireless sensor networks [5]. Consequently, existing irrigation procedures must be upgraded or replaced with advanced intelligent systems.

In particular, the Ministry of Water Resources of the Republic of Uzbekistan is in charge of 1693 irrigation pumping stations, based on which processes such as raising water to a higher level and delivering it over long distances are carried out. The working units of most pumping stations are morally and technically obsolete. Their profitability does not correspond to the level of demand. However, with the help of these old units, an average of 56 billion m^3 of water is raised to a higher level annually. Although these processes are partially automated in some areas, in most areas, the control is carried out manually under direct human supervision. In addition, the information received from the object for implementing control processes is often formed with large errors or approximately. This is how management makes the process of controlling the amount of water consumed at the level of demand uncertain. In addition, it remains a problem to obtain information about how much energy is consumed by the water supplied to each pumping station simultaneously. Due to the uncertainty and incompleteness of the information coming through the feedback network to the control object, the optimal form of control cannot be implemented. As seen from the above facts, one of the most important tasks is implementing management processes using limited resources. This, in turn, provides accurate and complete information about the state of the object, which can operate stably even in harsh climatic conditions, processing and storing information, and how much energy is spent on the water supplied to each pumping station simultaneously. Due to the uncertainty and incompleteness of the information coming through the feedback network to the control object, the optimal form of control cannot be implemented. 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In addition, from a technical point of view, the accuracy of these methods is somewhat low. Many firms and companies worldwide have proposed various smart devices to carry out measurements without direct human participation. For example, the Chinese company CXInstruments offers its CX-ULM ultrasonic level sensor for water level measurement, which has the following functions: human-machine communication function, digital temperature compensation, measurement and control function, wide voltage input and data transmission functions, the elimination of information jumps. The advantages of this sensor include its resistance to moisture, dust, high temperatures, alkaline gases, and other aggressive environments. However, it is relatively expensive at a price, and the reliability of long-term operation in the conditions of hydropower plants in Uzbekistan is somewhat lower. The HDL 700-C1 brand sensor offered through the HHCON Store is slightly cheaper. This ultrasonic level meter has advantages of level control, data transmission, and machine-to-machine communication. Its control box includes an industrial grade monolithic integrated circuit, digital temperature compensation, and more. Output signals can be analog or serial (RS485). However, the measurement accuracy of this sensor is below the required level. The JSN-SR04T level sensor of the EC Buying brand is assembled in a monolithic case and connected by a cable to a special controller. The absence of redundant elements increases the reliability of the sensor. However, the measurement accuracy of the sensor is somewhat low. In addition, a separate microcontroller or microcomputer is required to add some smart features to this sensor. This leads to a further increase in the cost of the sensor.

From the above analysis, it can be seen that in the climate of Uzbekistan, it is necessary to develop an intelligent device that is inexpensive, highly reliable, capable of remotely filtering, transmitting, and storing information, and capable of compensating for various disturbing influences, exposure, especially temperature, humidity, and dust. It includes the integration of the advantages of existing sensors and the complex elimination of their shortcomings.

2 Materials and methods

In irrigation systems, indirect measurement and intelligent calculation methods are used to measure the consumption of water flowing through covered channels with a constant cross-sectional area. In this, the level of flowing water is measured. Using developed information filtering algorithms, which separates useful information from unnecessary noise. Water consumption is calculated according to the water level and several other auxiliary parameters based on the algorithms entered into the device's memory. To evaluate certain uncertainties, parametric identification methods are used, and structural analysis methods are used to select a calculation algorithm. In addition to microcontroller software, intelligent filter libraries are used to implement theoretical calculations.

3 Results and Discussion

To solve the above problem, young scientists have developed an intelligent device that accurately measures the water level and sends information online for several years. It is worth noting what is included in the components of the proposed smart device and what functions they can perform.

It is advisable to use the MaxiBotix MB7580 ultrasonic range finder as a sensitive element of a smart device (fig.1). This meter can reduce the effects of condensation and freezing during continuous operation in a closed room or in a high humidity environment, measure to the millimeter, detect short and long distances, and have a reading speed of 0.6 Hz. And the output signal can be pulse width, analog voltage, or TTL series. In addition, this sensor has a compact and durable PVC housing that meets the IP67 waterproof standard.

a) b) c)

Fig. 1. Ultrasonic Rangefinder MB7580: a) top view; b) side view; c) bottom view.

It will be necessary to convert the signal received from the meter based on the UART protocol into the RS-485 protocol for the control controller (fig.2). This task is performed by the integrated circuit MAX 485. There are various options for the package of this microcircuit, and choosing the most compact one for this project allows us to reduce the dimensions of the overall control unit [11].

Fig. 2. MAX485 Integrated Circuit with SOP.

An uninterruptible power supply is required to ensure the continuous operation of the sensor. Most engineers use solar cells as a solution in addition to battery backups where a constant source is required. It is best to charge the battery with solar energy. The LTC3105 converter can be used as a solar battery charger [12, 13, 14]. A standard electrical circuit has been proposed (fig.3).

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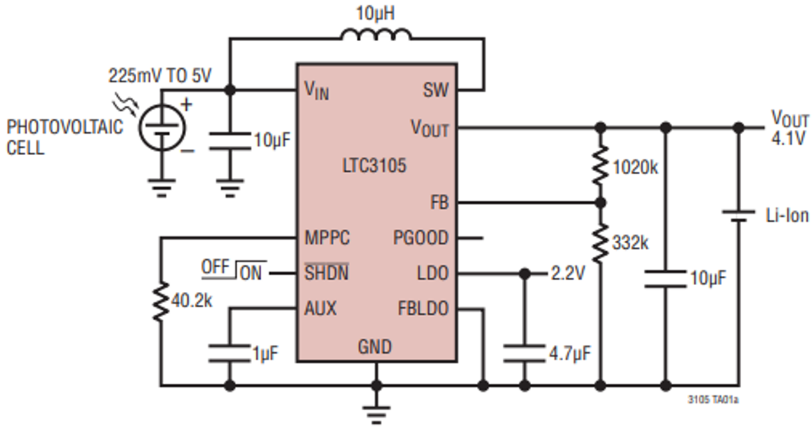

Fig. 3. LTC3105 Battery Charging Converter Schematic Diagram.

The services of mobile operators are used for the remote transmission of received information over a communication channel. Thus, the problem of reliable wireless reception of information over long distances is solved. At the same time, since different companies have different antennas for receiving signals in different regions, it is considered appropriate to be able to connect to at least two companies [15]. This connection can be made via the SIM868 module (fig.4). The SIM868 module is a complete quad-band GSM/GPRS module that also includes GNSS technology for satellite navigation. The compact design with LCC and LGA pads saves time and money in developing GNSS applications.

Fig. 4. SIM868 module.

Since some irrigation pumping stations in Uzbekistan are located far from residential areas, mobile operators' signals in these areas may be very weak or nonexistent. In such situations, LoRA technology (fig.5) provides a continuous communication exchange, albeit at a low speed [16, 17, 18].

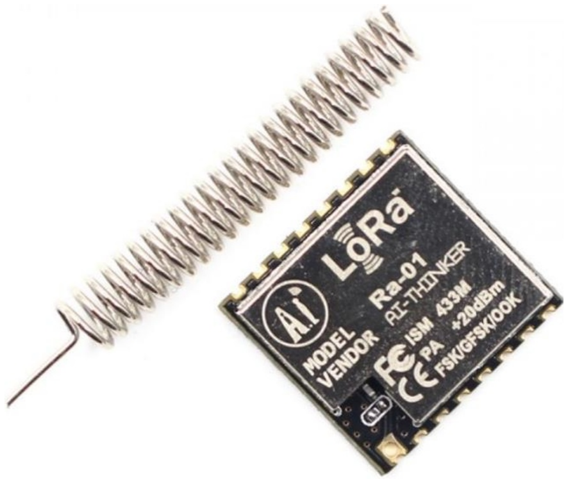

Fig. 5. LoRa module and its antenna.

Even when exchanging information with the server for some reason becomes impossible, the smart device must take measurements offline and store all the data in its memory. And for this, you need a storage device. XTSD01G can be used as a storage device because of its low cost, small size, and sufficient performance reliability (fig.6). The 128MB memory type of this unit can store long-term data.

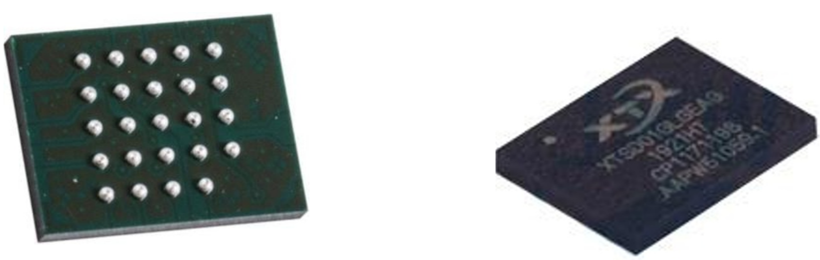

Fig. 6. Memory unit XTSD01G.

The STM32L151RCT6 microcontroller is the preferred solution for combining all the elements and performing the control task (fig.7). This microcontroller is 32-bit and has 256 KB of flash memory. In addition, this microcontroller is efficient for battery life as it requires very little power. Typically, microcontrollers belonging to this class are widely used in the following projects:

- medical and hand tools;
- application management and user interface;
- computer peripherals, games, GPS, and sports equipment;
- alarm systems, wired and wireless sensors;
- communal accounting.

Fig.7. STM32L151RCT6 microcontroller.

The intelligent level sensor can measure the water level in open channels and rivers and calculate the water volume (fig. 8). It will be equipped with a GSM module for online data transmission to the server.

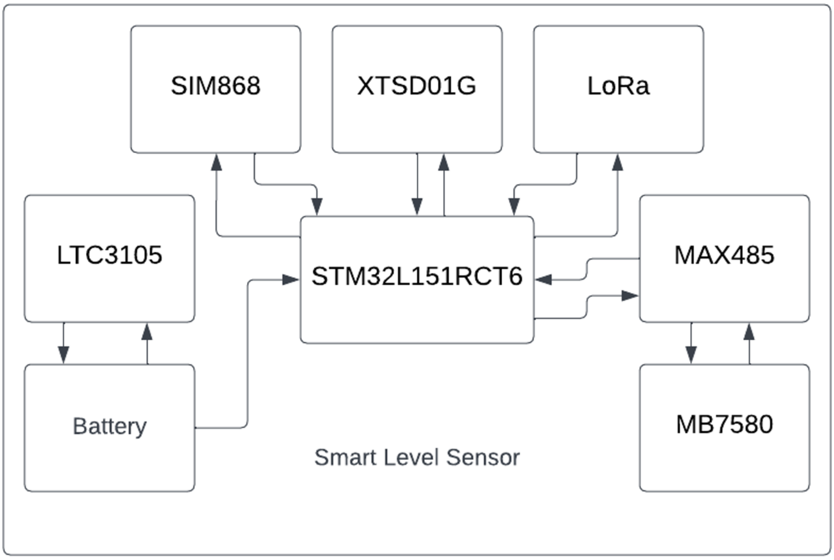

Fig. 8. Structure of an intelligent level sensor.

The intelligent level sensor can measure the water level and calculate the volume of water in open channels and rivers. It will be equipped with a GSM module for online data transmission to the server. This sensor works completely independently of any power source as it contains a solar panel and a rechargeable battery. For the sensor to work correctly, you need to install it correctly and insert a SIM card that works with a 2G connection. An industrial sample of the sensor is shown in Figure 9.

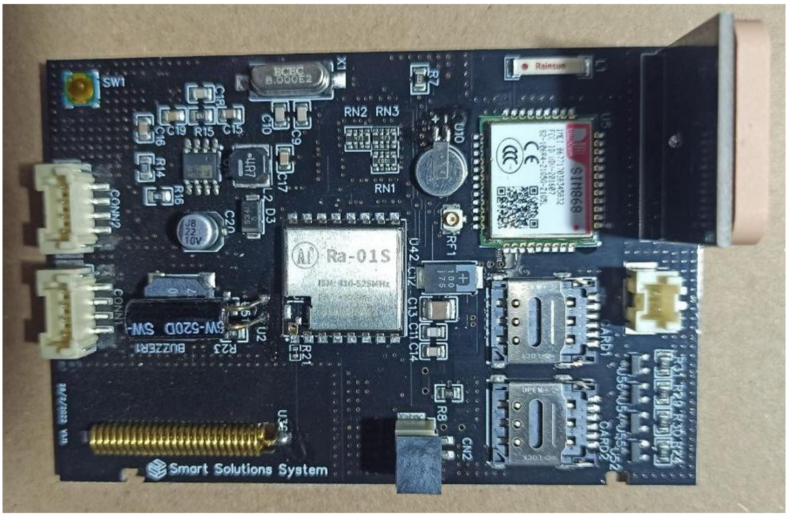

Fig.9. Industrial sample of intelligent level sensor board.

An industrial sample of the developed intelligent level sensor was created and successfully passed laboratory tests (fig. 10).

Fig. 10. Industrial example of smart level sensor.

At the same time, according to the Law of the Republic of Uzbekistan "On Inventions, Utility Models, and Industrial Designs", the developed utility model of the water level control system was patented by the Ministry of Justice of the Republic of Uzbekistan, and copyright was protected by law [19]. For the operation of this smart device, a unique program was developed, for which a certificate was obtained from the Intellectual Property Agency under the Ministry of Justice of the Republic of Uzbekistan [20]. The smart device was tested and certified by the National Certification Center of the Republic of Uzbekistan [21], and permission was obtained for its mass production. To date, the enterprise of

Uzbekistan LLC "Smart Solutions System", produces two types of intelligent level gauges, which differ in the measurement range. The devices' main technical and metrological characteristics are given below (Table 1).

Table 1. Main technical and metrological characteristics of devices.

Characteristic name	Device model	
	SMART WATER-SW 5	SMART WATER-SW 20
Level measurement range, mm	from 0 to 5000	from 0 to 20000
Permissible limit of the given standard error, mm	±0.4	±0.4
Accuracy class	4	4
Radiation angle, degrees, at least	53	
Supply voltage in an autonomous power source (battery), V	18 to 36	
Power consumption, W	0.065	
Working temperature, °C	-15 to +50	
Overall dimensions, mm, not large: - length - width - height	 85±0.3 175±0.5 60±0.2	
Weight, g, not more	1000	

At present, intelligent level sensors have been installed in more than 3,000 irrigation canals in Uzbekistan (Fig. 11).

Fig. 11. Intelligent level sensors installed on the irrigation canals.

These devices have been operating in real conditions for the last three years with a given accuracy within their technical specifications. This, in turn, allows you to determine the parameters necessary to monitor pumping stations and evaluate their efficiency in real-time. In addition, these devices from domestic manufacturers have advantages over their imported counterparts due to their low cost, customization options' availability, and easy adaptation to difficult conditions. At the same time, all the problems identified during the operation of the devices are studied from a scientific and technical point of view.

The graphs below show the processes of intelligent filtering of noisy signals, in which the optimal filtering algorithm is selected automatically based on the program included in the smart device. The signal shown in blue in the graphs represents the noise being generated. The red line shows the filtering result. Information is received by measuring 5 times per second. The received information is passed through various filtering algorithms.

For this process, the device found the structure of three consecutive filtering blocks to be optimal. The information filtering processes in it were carried out in the following order: Fig. 12a. The signal obtained from the primary filtering unit, Fig. 12b. The signal obtained from the secondary filtering unit, Fig. 12s. The signal received from the tertiary filtering unit.

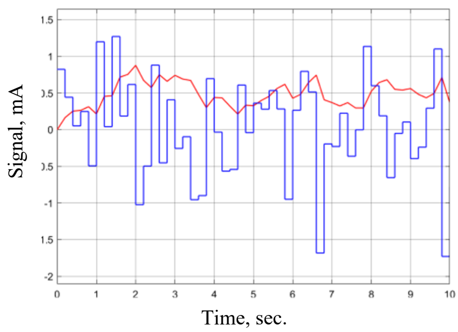

Fig.12a. Filtering result 1.

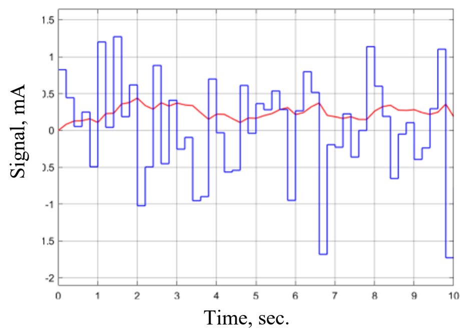

Fig. 12b. Filtering result 2.

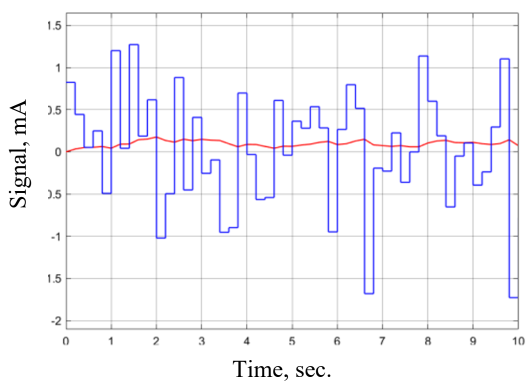

Fig. 12c. Filtering result 3.

The results show that the stabilization of received signals is improved by 74.2% due to intelligent filtering algorithms in a smart device. The reliability of information decreased by 8.2% in total.

4 Conclusions

As a result of the experimental studies, the following conclusions can be drawn:

1. The manufactured device is designed to work in harsh continental climates, perform high-precision measurements even in extremely hot and extremely cold conditions, have the functions of remote transmission of information, and, if necessary, store information. An in-memory archive prevents data loss even when it cannot be transferred over a distance due to certain external influences.
2. The industrial sample of the device was tested and certified in laboratory and field conditions and in the national certification center of the Republic of Uzbekistan, and

permission was obtained for its mass production.
3. Since domestic manufacturers produce intelligent level meter, its price is reduced by 42.7% compared to imported analogs.
4. As a scientific novelty of the work, it is possible to recognize the intelligent filter algorithm developed for filtering information measured by a smart device. As a result, the stabilization of received signals is improved by 74.2% due to the use of intelligent filtering algorithms in a smart device. The reliability of information decreased by 8.2% in total. This result is less than the 9.5% target for information reliability.

Acknowledgments

This publication has been produced within the framework of the Grant "Energy efficiency monitoring system of operated irrigation pumping stations in Uzbekistan", funded under the MUNIS Project, supported by the World Bank and the Government of the Republic of Uzbekistan. The statements do not necessarily reflect the official position of the World Bank and the Government of the Republic of Uzbekistan.

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