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PSOC4 BASED INTELLIGENT WATER CONSUMPTION METER

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***Abstract*: An intelligent water consumption meter system has been designed. The measurement system has been developed using Cypress Semiconductor PSoC4™ system-on-a-chip. The hardware part has been designed to perform water flow measurements, temperature and pressure monitoring. Developed Android application has been used to communicate with hardware using the Bluetooth LE interface. Overpressure detection procedure was developed to prevent emergency cases. The user has been able to monitor water use in real-time, configure system remotely and control external pipe valve. Advanced mode has been added to reset measuring results, select liquid type and recalibrate system should it be necessary.**

***Index Terms*: Bluetooth, smart home systems, PSoC4, system-on-a-chip, water consumption.**

I. INTRODUCTION

Water is a resource we use every day, but we often pay no attention to how we use it and how we depend on it. Today water plays a key role in our daily lives and it often goes unnoticed. As consumers, the only one relationship we have with water is the monthly water bill, which does not give us the ability to fully understand water usage behavior and habits.

Now more than ever, smart home devices are providing us with valuable information about how we live. Currently, homes can help us understand and regulate temperature, adjust lighting, monitor security etc. We live smarter because our home is smarter.

The intellectual water consumption meters will give us insights into house water usage, like we have never seen before. With the use of intelligent water meters, we can in real time find out what amount of water is used in the house and gives us ability to better understand what percentage of water is spent on shower, washing, cooking, irrigation system etc. In addition, such systems instantly protect the house from leaks and save money. The collection of statistics gives ability to determine peaks of water consumption and to correlate them with specific parts of the day or days of the week.

Intelligent water meters change the relationship with water, provide complete information on the use of water and provide the ability to control its use, which has never been before.

Using such systems, we feel more connected to the home and can understand where and how to save money in water bills.

Some of modern intelligent water systems can be connected to wireless networks using Wi-Fi, Bluetooth. It allows us to constantly monitor the use of water, even when we are not at home.

In addition to smart home applications, smart water meters have been used in businesses where, due to the high complexity of the water supply system, it is not possible to monitor water use or detect leakages on time.

Currently, a market of smart home systems offers systems based on different measurement principles [1]. Industrial flow meter usage diagram is shown in Fig. 1.

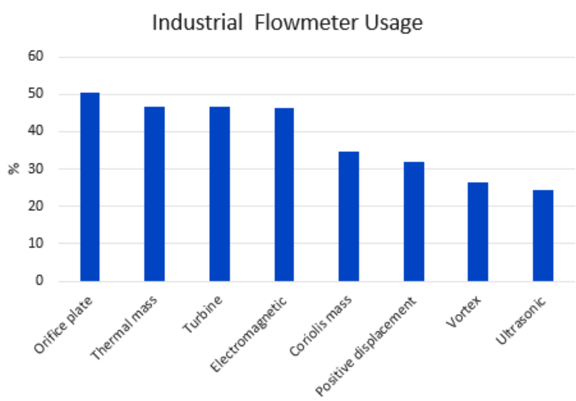

Fig. 1. Digital Flow Meter (Flow range 1-25 L/min) with temperature sensor and LCD

The most common in smart homes are Hall-based turbine flow meters and ultrasonic flow meters. Both types come with a microcontroller that handles sensor readings and calculates such metrics as flow, total consumption etc. Depending on the user interface, the results may be displayed or transmitted to a mobile device. Turbine flow meters are used in a wide variety of liquid and gas flow sensing applications [2]. They can be built to endure high pressure, and high and low temperatures. They have very compact design, expanded measuring range and offer a high turn-down with minimum uncertainty and excellent repeatability. Turbine flowmeters are also simple to install and maintain only requiring periodic recalibration and service.

Ultrasonic flow measurement can be very accurate and is used for custody transfer of natural gas and petroleum liquids [3]. High turndown, handling high pressures, repeatable, handling extreme temperatures, can be used clamped to the outside of a pipe without penetration, low maintenance, highly reliable and self–diagnosing. Disadvantages can include high cost, sensitivity to stray process vibrations, problems with pipe diameter change due to buildup and clamp-on units which have lower accuracy.

Ultrasonic flowmeters do not obstruct flow so they can be applied to sanitary, corrosive and abrasive liquids. Some ultrasonic flowmeters use clamp-on transducers that can be mounted external to the pipe and do not have any wetted parts. Temporary flow measurements can be made using portable ultrasonic flowmeters with clamp-on transducers. The use of clamp-on transducers introduces additional ultrasonic interfaces that can affect the reliability and performance of these flowmeters.

While considering modern intelligent water consumption meter system next three main types can be highlighted:

1) Digital water consumption meters

Such devices include a simple mechanical flow meter based on the Hall sensor, display module to indicate measurement results and a few controls to configure device or switch between modes. A simple digital flow meter is shown in Fig. 2.

Fig. 2. Digital Flow Meter (Flow range 1-25 L/min) with temperature sensor and LCD

2) Digital water consumption meters with wireless connectivity

Unlike the previous type of systems, devices of this type additionally have a wireless interface to transmit the measurement results to the outside. Measurement of water use might be performed mechanically with the Hall sensor or with the using of ultrasonic sensors. Depending on the complexity of the system, the water consumption metrics information is being transferred to mobile application or to a web server. Device setup and water use monitoring is done remotely via a smartphone or through a web interface. Display and controls are optional. Some of the modern systems have ability to learn water use signatures to recognize different usage categories (Fig. 3 and 4).

Fig. 3. FLUID – Wireless Ultrasonic Flow Meter

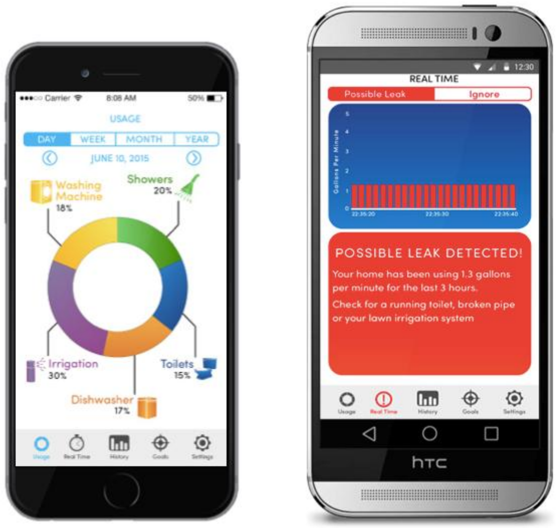

Fig. 4. FLUID – Mobile application interface

3) Smart Home Monitoring Systems

Smart Home Monitoring systems besides water consumption measurements perform power monitoring, heating system control, air conditioning control, adjust lighting etc. Configuration and metrics monitoring are done remotely via mobile Android/iOS application or Web interface. Such systems are complex and expensive. Structure of complete Smart Home monitoring system is shown in Fig. 5.

With considering such criteria as cost, compactness and measurement processing the Hall-based turbine flow meter has been selected to develop prototype of intelligent water consumption system with wireless connectivity. The developed system is intended for being used as a separate subsystem of a smart home.

II. BASICS OF FLOW MEASUREMENTS

Turbine flowmeters measure flow on a volumetric basis. Turbine flowmeters are applicable to clean fluids over a wide pressure and temperature range. Usually turbine flow meters produce output signals that are electronic pulses but other output analog or digital are available [4]. The turbine rotor, mounter on a shaft, rotates when fluid passes through the turbine meter. The turbine meter is provided with an electrical pickup which detects the rotation of its rotor and then transforms this speed of the turbine rotor into pulses. Simple turbine flow meter functionality is shown in Fig. 6.

Fig. 5. SmartMAC system architecture

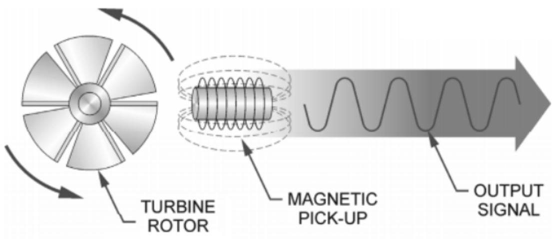

Fig. 6. Turbine Flow Meter

The number of pulses generated is given as:

$$n_p = \frac{T_p f}{Q}, \tag{1}$$

where n_p – pulses per volume unit; T_p – time constant in minutes; Q – volumetric flow rate and f – frequency in Hz.

Also, the relationship between volumetric flow rate of the turbine flowmeter and the frequency of the pulses generated by the pickup sensor can be expressed in form of the equation:

$$f = kQ, \tag{2}$$

where k – "K" factor of the turbine meter (e.g. pulses per liter). With taking into account (1) turbine "K" factor can be calculated as:

$$k = \frac{n_p}{T_p}. \tag{3}$$

III. HARDWARE COMPONENTS

Most modern intelligent water flow measurement systems contain the following key components:

- Water Flow sensor.
- Temperature Sensor.
- Pressure Sensor.
- Display module.
- MCU/SOC based computing IC.
- Wireless interfaces.

A. FLOW SENSOR WITH TEMPERATURE SENSOR

Turbine flow meters are based on turbine flow sensors. To develop prototype system YF-B6 flow sensor was selected. Table 1 includes basic flow sensor parameters.

Table 1

YF-B6 Flow Sensor

#	Parameter	Value
1	Flow rate	1~30 L/Min
2	Flow pulse	F=6.6*Q, Q = L/Min
3	Working voltage	DC 3V~18V
4	Working current	15mA
5	Suffering pressure	Max 1.5 Mpa
6	Working temperature	-40 C ~ +80 C
7	Min Insulation Resistance	100MOhm
8	Output Pulse Duty Cycle	50 % ±10 %
9	Max output Pulse Voltage	>DC 4.7V (input voltage DC5V)
10	Min Output Pulse Voltage	<DC 0.5V (input voltage DC5V)

Pinout connection is shown in Table 2

Table 2

YF-B6 Pinout Description

Pin Number	Pin Description
1 (Red)	Vdd "+"
2 (Black)	Vout "- "
3 (Yellow)	Gnd
4	NTC Temperature sensor P1
5	NTC Temperature sensor P2

Per [5], there are 2 basic circuits for temperature detection and temperature compensation. Circuit that was used to connect temperature sensor is shown in Fig. 7.

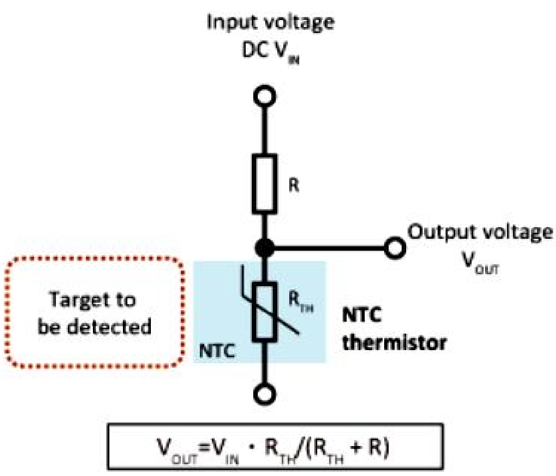

Fig. 7. Temperature sensor connection circuit

B. PRESSURE SENSOR

For monitoring water pressure an advanced pressure transductor was selected. The transducer allows to measure different fluid pressure in 0~150 psi range. Output voltage is linear and proportional to fluid pressure: 0 psi outputs 0.5 V, 50 psi outputs 2.5 V and 100 psi outputs 4.5 V. The pressure transductor has 3 wires for connection: Red for +5 V, Black for GND and Blue for signal output. Selected pressure transductor is shown in Fig. 8.

Fig. 8. Temperature sensor connection circuit

C. OLED DISPLAY

Measurement data visualization can be executed using any type of displays. The best choice for system prototyping is 0.96” OLED Display module 128x64. That module requires only 4 I/O to connect with MCU using I2C serial interface. Module driver library is available in internet and is compatible with common MCU/SOC vendors.

Fig. 9. OLED 0.96” Display Module

D. CY8CKIT-042BLE

The CY8CKIT-042-BLE-A Bluetooth® Low Energy (BLE) Pioneer Kit is a development platform that allows user to evaluate and develop BLE applications using the best-in-class PSoC® 4 family devices from Cypress Semiconductor company. The BLE Pioneer Kit offers footprint-compatibility with Arduino. In addition, the kit features a CapSense® Slider, and RGB Led, a push-button switch, an onboard programmer-debugger and USB-UART/I^{2}C bridge functionality block, a coin cell battery holder, and Cypress F-RAM [9]. The BLE Pioneer Kit supports 1.9 V, 3 V, 3.3 V, or 5 V as operating voltages. The BLE Pioneer Kit supports the PSoC4 BLE device which is a 32-bit, 48-MHz Arm® Cortex®-M0 BLE solution with CapSense, 12-bit analog front end (1x SAR ADC, 4x low-power op-amps, 2x low-power comparators, and 2x current DACs), 4x TSCPWM, 2x SCB, 4x UDB, LCD, I2S, and 36 GPIOs. PSoC 4 BLE provides a complete solution for sports and fitness monitors, wearable electronics, medical devices, home automation systems, and sensor-based low-power systems for Internet of Things (IoT). The BLE Pioneer Baseboard consists of the blocks (Table 3) shown in Fig. 10.

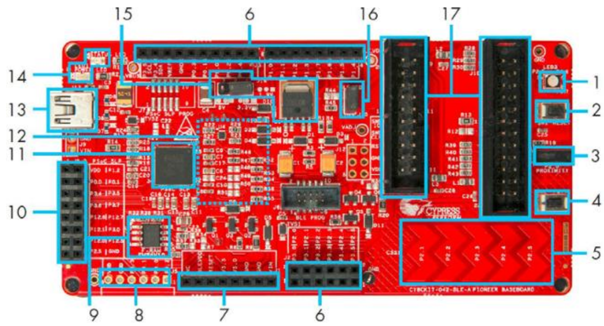

Fig. 10. BLE Pioneer Baseboard

Table 3

BLE Pioneer Baseboard Blocks

#	Block name
1	RGB LED
2	BLE device reset button
3	CapSense proximity header
4	User Button
5	CapSense slider
6	Arduino-compatible I/O headers (J2/J3/J4)
7	Arduino-compatible power header (J1)
8	Diligent Pmod-compatible I/O header (J5)
9	Cypress F-RAM 1Mb (FM24V10-G)
10	PSoC 5LP I/O header (J8)
11	PSoC 5LP programmer and debugger (CY8C5868LTI-LP039)
11	Coin cell holder (bottom side)
12	USB connector (J13)
13	Power LED and Status LED
14	System power supply jumper (J16) – LDO 1.9V-5V
15	BLE power supply jumper/ current measurement (J15)
16	BLE module headers (J10/J11)

Besides baseboard the CY8CKIT-042-BLE- A includes CY5677 CySmart BLE 4.2 USB Dongle. The

BLE Dongle is used to debug BLE communication in pair with CySmart PC application. BLE Dongle Markup is shown in Fig. 11.

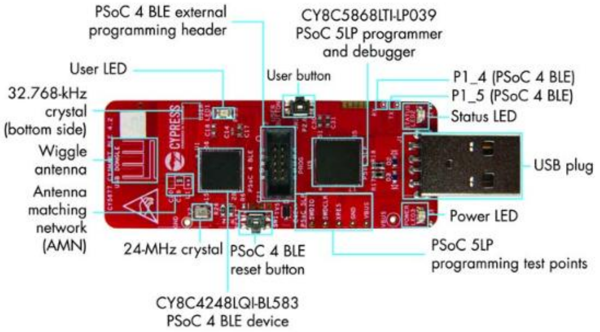

Fig. 11. BLE Dongle Markup

IV. SYSTEM DESIGN

Considering wide range of existing types of water flow meters [10-14] the intelligent water consumption measurement system should give user ability to get real-time water flow value, water temperature, pressure. All measured data are collected and transferred to mobile device on request. As advanced hardware feature external lines are provided to control pipe valves.

The block diagram of the system architecture with features listed above is shown in Fig. 12.

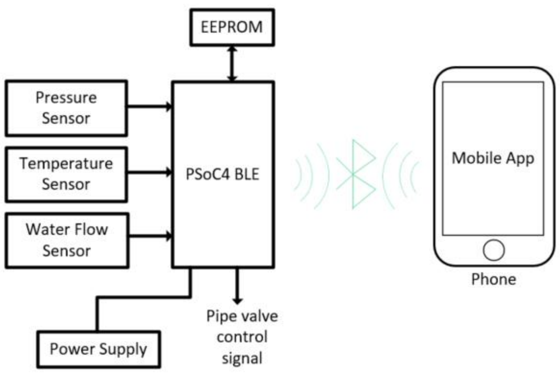

Fig. 12. High-level block diagram of intelligent water consumption meter system architecture

External EEPROM memory is used to store system settings and accumulate measurement results.

In addition to the real-time water consumption measurement, the developed smart meter provides the user with additional functionality such as:

- Emergency events processing.
- Master mode for system calibration, configuration and system reset.

High-level PSoC4 firmware flow diagram that supports features listed above is shown in Fig. 13.

Afterwards, power on system initialization is performed. Then, PSoC4 device starts to measure temperature, pressure and water flow in forever program loop. After each measurement stage emergency state detecting and processing procedure is executed. Water consumption metrics displaying, and system configuration procedures are optional, and they are called only when required hardware components (OLED display) are available and/or requested from user side (Mobile Application usage).

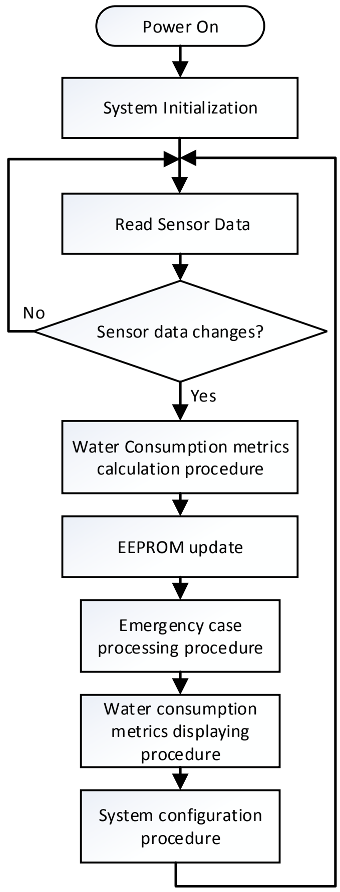

Fig. 13. High-level flow diagram

The PSoC Creator 4.2 IDE was used to develop firmware of the intelligent water consumption meter. The PSoC Creator project design schematic is shown in Fig. 14. Per design schematic project structure was divided into three component groups:

- Sensor Data Processing.
- Bluetooth Communication and Data Storage.
- User Interface.

The sensor data processing groups are responsible for processing analog signals from temperature and pressure sensors, as well as for calculating impulses from the flow sensor. Bluetooth communication and data storage group are responsible for wireless communication if available and EEPROM data storage.

The user interface group includes OLED driving and button switch processing logic.

Bluetooth communication and OLED driving logic with button switches are optional features and might be enabled/disabled in source code.

To process analog signals from temperature and pressure sensors the Sequencing SAR ADC with 3 channels was enabled. The channel 0 and channel 1 were used to measure analog voltages from temperature sensor circuit. The channel#0 is used to measure V_{out}, the channel#1 is used to measure V_{in} (see Fig. 7).

Measured voltages are used to calculate R_{TH} value by using next equation:

$$R_{TH} = \frac{V_{out} R}{V_{in} - V_{out}}. \tag{4}$$

The Timer Counter component was used to calculate flow meter sensor pulses. With considering the YF-B6 flow pulse/flow rate relation (see Table 1) the maximum pulse frequency will be 198 Hz. The timer component was configured as 16-bit counter with 12MHz clock signal. Such settings allow to configure different flow rate update period (maximum is once per 5.5 minutes).

The Bluetooth communication and data storage group implement wireless communication and data storage. The LED_PWM component is used to drive BLE Adv LED that indicates Bluetooth advertisement process. The Em_EEPROM component is used to store latest measurement results and system settings when device goes into low power mode or switches off.

The User interface group includes I2C_OLED component that is I2C bus master driver. This driver communicates with external OLED display that shows measurements results and implements simple menu to configure system settings using button switches. Two LEDs were added to indicate system state.

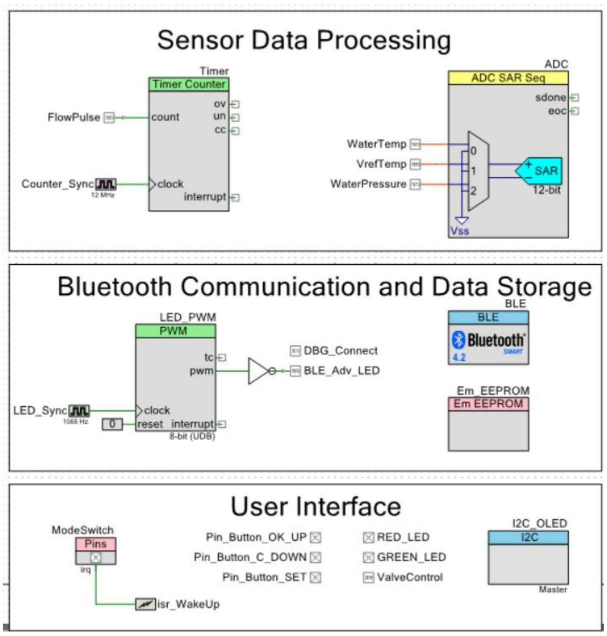

Fig. 14. PSoC Creator Project Design

The designed system includes emergency state processing logic. There were 3 user cases that are covered in the system source code:

- Over pressure detection.
- Under pressure detection.
- Leakage detection.

Overpressure and under pressure detection analyze water pressure and compare it with Min/Max values. These values are configurable and can be changed using OLED-based menu or the BLE application.

The system periodically measures pressure and if it is bigger than Max value, the pipe valve control signal is set high and the red LED switches on to indicate error. As soon as pressure reduces the pipe, valve control signal goes low. The same procedure is executed when measured pressure is lower than Min value. In this case the pipe valve control signal is set high when under pressure is detected and is set low when pressure increases over Min value. Under pressure detection works only if water is not consumed.

The leakage detection procedure analyzes the flow meter data and pressure valve, but it is activated by user when it leaves home. If leakage detection is enabled, any pulses that come from flow meter and pressure reducing mean that water is consumed in some way. In this case, system sets pipe valve control signal high and waits for user input. It is expected that pipe valve control signal closes pipe valve and stops water consumption. Manual reset is required to return system into normal operation mode. The emergency state processing procedure flow diagram is shown in Fig. 15.

As it was described above, visualization of measurement results might be done using OLED display or BLE application. The system source code supports both options but at least one of them should be available.

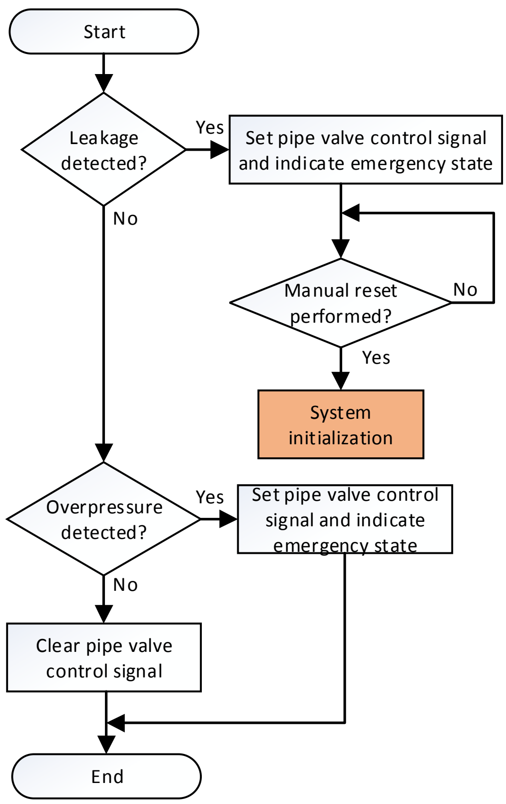

Fig. 15. Emergency state processing procedure flow diagram

Data visualization flow diagram is shown in Fig. 16.

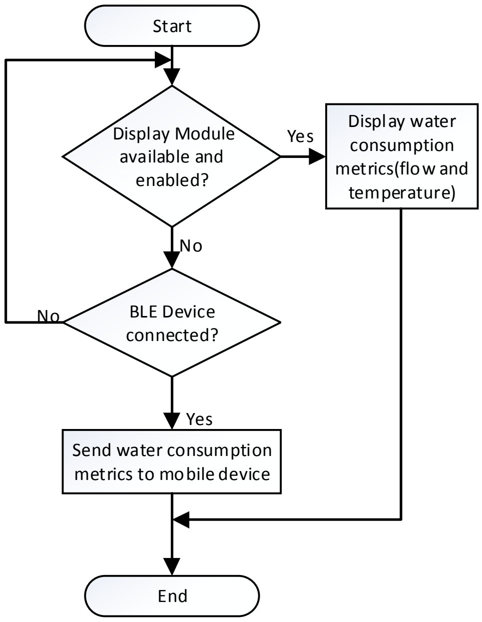

Fig. 16. Water consumption metrics displaying procedure flow diagram

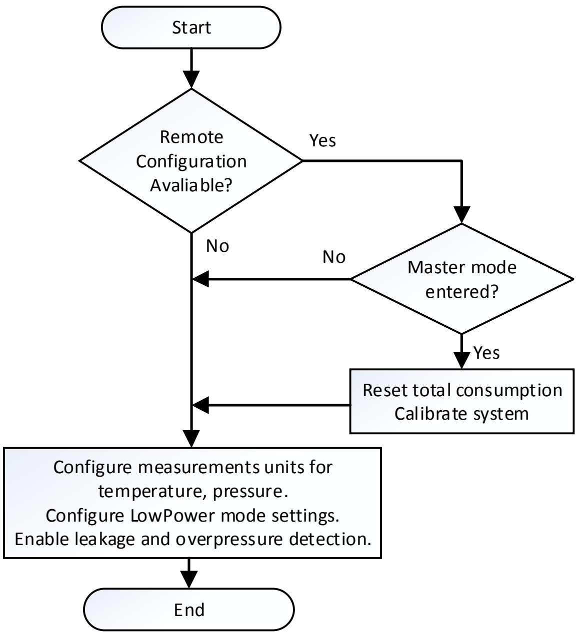

Fig. 17. System configuration procedure flow diagram

System configuration might be done remotely by using BLE application or using onboard button switches with OLED menu. Both options are available but at least one of them should be available. Expect user mode where basic setup is done, the designed system has master mode implemented. In this mode user has ability to reset total consumption and calibrate system. Calibration might be done for flow meter, temperature sensor and pressure sensor. Master mode entrance is protected by password to prevent system to be configured by unauthorized person. With master mode the designed system might be used in central water accounting.

The BLE Android application was developed as a part of intelligent water consumption system. It uses Bluetooth Low Energy wireless interface to communicate with device, receive measuring results and send updated configuration.

The mobile android application flow diagram is shown in Fig. 18.

V. FUNCTIONAL AND PERFORMANCE VERIFICATION

System configuration might be done remotely by using BLE application or using onboard button switches with OLED menu.

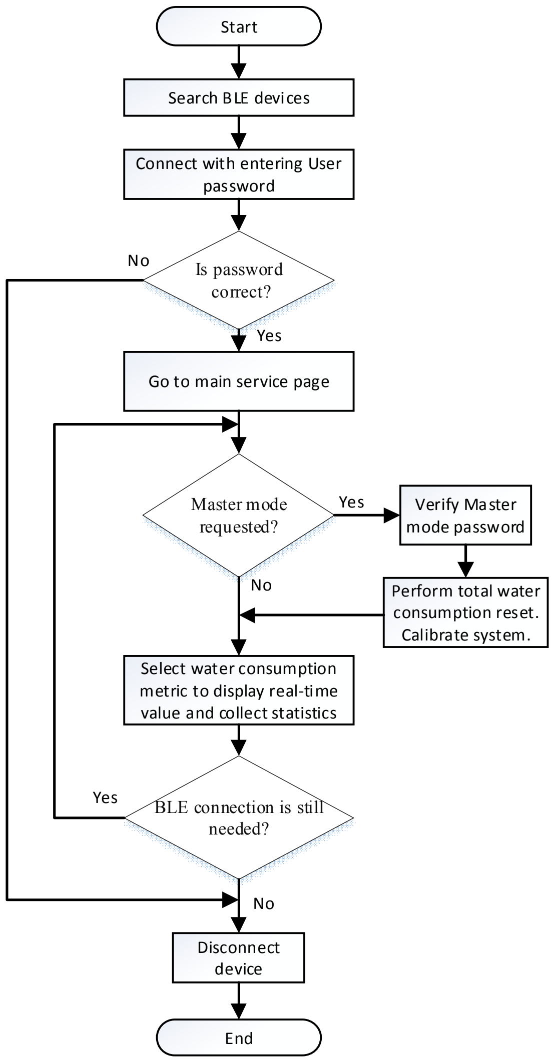

Fig. 18. Mobile application flow diagram

Functional and performance tests were conducted to verify the functionality of the developed intelligent water consumption meter. The following tests were performed to check functionality of the developed measurement device:

- Water consumption accuracy tests.

- Results visualization tests.
- Remote wireless configuration tests.
- User interface tests.
- Under pressure, overpressure and leakage stress tests.

System verification setup that is shown in Fig. 19 was developed to cover all system verification test.

Verification setup includes next additional components:

- Reference turbine-based mechanical water consumption meter.
- Water pump with adjustable pressure.
- L298N pump driver.
- Water tank filled with water.
- Set of water pipes and fittings.
- External 5V/12V power supply to power on PSoC 4 BLE and water pump.

The set of water pipes and fittings were used to connect flow meter, pressure and temperature sensors. Water tank was used to emulate native water flow that is present in water distribution system. The pump driver was used as an external pipe valve. In case of under pressure, overpressure and leakage detection, PSoC 4 BLE generates high level signal to switch off pump. Additionally, available manual pressure adjustment was used to simulate overpressure and under pressure events. Reference water consumption meter was used during accuracy verification.

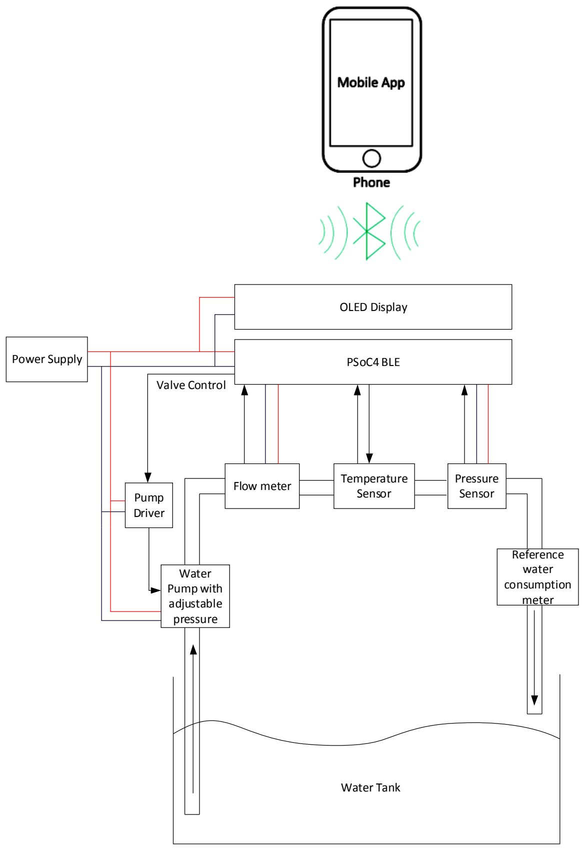

Fig. 19. System verification setup

Wireless configuration and data visualization were done by using android smartphone with installed BLE application that was developed to communicate with PSoC4-based measurements device. Data visualization results for BLE application is shown in Fig. 20.

Accuracy verification was done for 1L, 5L and 20L water volumes. Results are shown in Table 4.

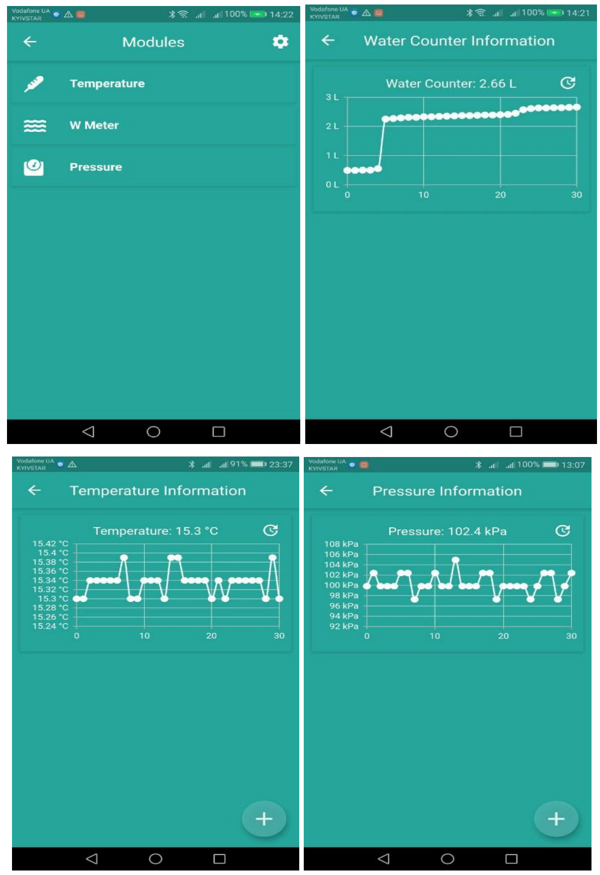

Fig. 20. Mobile application data visualization

Fig. 21. OLED data visualization

Table 4

Measurement accuracy results

#	Reference meter value, L	Measured value, L average	Accuracy, %
1	1	0.98	2
2	5	4.81	3.8
3	20	19.2	4

VI. CONCLUSION

The modern types of water consumption measurement systems have been described and analyzed in this article. The architecture of the intelligent water consumption system was designed by considering the disadvantages and advantages of the most popular systems.

A PSoC4-based intelligent water consumption meter was developed based on the developed architecture. Measuring results are displayed on an OLED display or transferred to the mobile android application using Bluetooth Low Energy interface.

The designed measurement device can be configured using onboard button switches. The simple user menu was developed for that purpose. Additionally, the designed system can be configured using mobile application.

Advanced procedures were developed to detect overpressure, under pressure and water leakage emergency events.

Performance and functionally verifications were executed. During that, tests showed that display usage is not as effective as remote visualization and configuration using wireless communication Bluetooth interface.

Accuracy validation shows that developed system has some accuracy degradation comparing with mechanical turbine-based reference flow meter. It was investigated that internal structure makes big influence on the measurement accuracy and better flow sensor should be used for measurements.

The under pressure, overpressure and leakage detection procedures have proven their efficiency during the stress tests.

In general, the developed intelligent water consumption meter is an effective solution for personal use.

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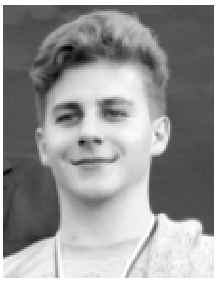

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