MULTISENSOR PROTOTYPE FOR BEVERAGE QUALITY CONTROL: PRINCIPLE SCHEME AND TEST RESULTS

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Abstract: *Nowadays there is no general theory of wireless sensor networks, and existing mathematical models are fragmented. Therefore, together with the development of theoretical foundations and testing them on appropriate mathematical models, it is necessary to work out design solutions for multisensors and sensor networks on physical models or prototypes. It is envisaged that the multisensor will be delivered to the market with a set of interchangeable sensor modules with ability of quick replace them when moving from one series of measurements to another in order to speed up the process of controlling beverage quality at all stages of production. The results of testing circuit solutions and test methods based on the prototype multisensor for real-time monitoring of the quality of beverages are presented in this publication.*

Keywords: *wireless smart multisensor networks, test of beverage quality*

ITHEA Keywords: *J.3 Life and Medical Sciences- Biology and Genetics.*

Introduction

"Smart" multisensors and biosensor systems based on modern information and communication technologies make it possible to qualitatively improve the parameters of systems for testing biologically active, chemical and toxic substances, biological or biophysical objects, and improve the parameters control, processing and analysis of data in the food industry, specifically in beverage production, digital agriculture, environmental monitoring and other areas of human activity. It should be noted that sensor technologies are one of the key world technologies, the development of which is exponential, that is, the parameters of these technologies improve by tens or even hundreds of percent per year. In addition, if it is possible to use such technologies in conjunction with, for example, IT and microelectronics then there is a programmed technological explosion. According to IoT Analytics [Smart, 2019], in 2019, 14% of all meters are now smart meters. The market of “smart” meters increases every year and this increasing is predicted for many years further. This market includes smart sensors and smart devices that can operate individually or as part of wireless or wired sensor networks, for measuring electrical parameters as well as parameters of the liquid and gas environment. In the next two years, this market is expected to increase by another 1 billion smart sensors, including bio- and multisensors. The main idea of the article is to show the results of circuit design and testing prototype of wireless "smart" multisensors based on amperometric enzyme biosensors to control the quality of beverages including during their production.

Work objectives

Work objectives are design and prototyping the smart biological sensor with wireless data communication unit for quality control of beverages.

Smart biosensor design

The world's leading companies of electronic components market have been working successfully over the last few years to create new microcontrollers designed to work with electrochemical modules including bio- and multisensors. The leader among such companies is the Analog Devices Company, which at the beginning of 2019 put into production a new chip of the microcontroller ADuCM355 [Analog, 2020]. The block diagram of the microcontroller is shown in Figure 1.

This microcontroller is designed to work with electrochemical and biosensors. It is based on the ARM® Cortex®-M3 processor core and can operate in current, voltage and resistance measurement modes. The microcontroller contains a 16-bit ADC, filter, amplifier with programmable gain, trans-impedance amplifier with programmable gain to connect sensors of different types, three DACs with outputs on voltage, direct access controller to independent interfaces, UART port and I2C interface.

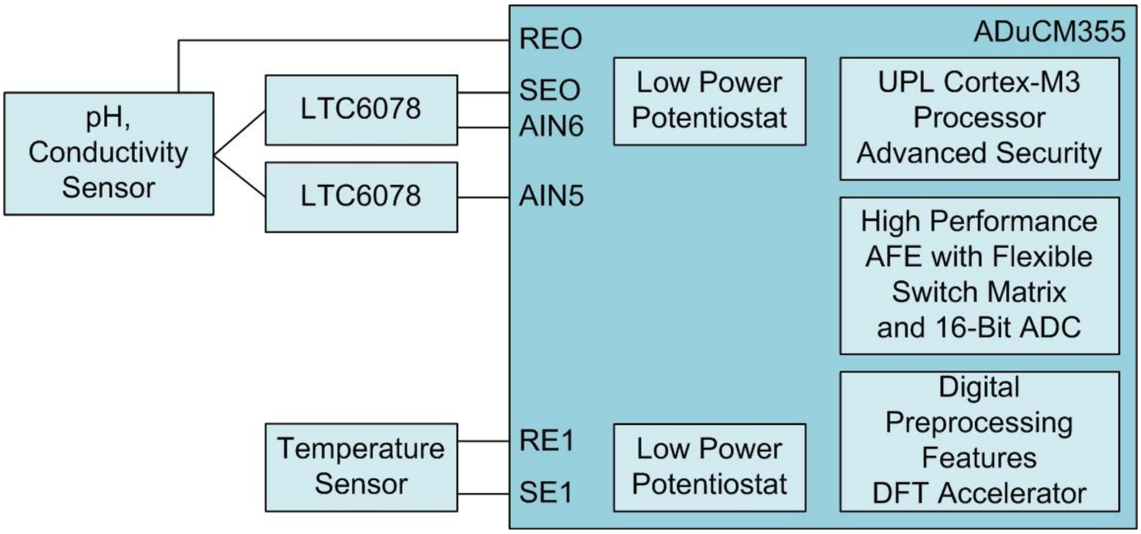

Figure 1. Block diagram of the ADuCM355 microcontroller

Most electrochemical and biosensors can be directly connected to the microcontroller. Additional LTC6078 type amplifiers can be used to increase the sensitivity of the measuring channel. This is a dual-rail input-output CMOS low-noise amplifier with low power consumption. The amplifier has large input impedance that allows it to be successfully matched to the high output impedance of the biosensor to provide the required measurement accuracy. When working with electrochemical or biosensors, it is usually necessary to control the ambient temperature in order to compensate the sensor temperature error. Such microcontroller also allows the measurement of the impedance of the sensors in the range from 100 Ohms to 10 MOhms. The large dynamic range is especially important for determining the electrical conductivity, which allows measuring different concentrations of the test solutions. It should be noted that multisensory prototype was created on the base of the previous microcontroller ADuCM350, which is fully compatible with the new ADuCM355.

Multisensor functional diagram

The multisensor functional diagram with the main blocks is shown in Figure 2.

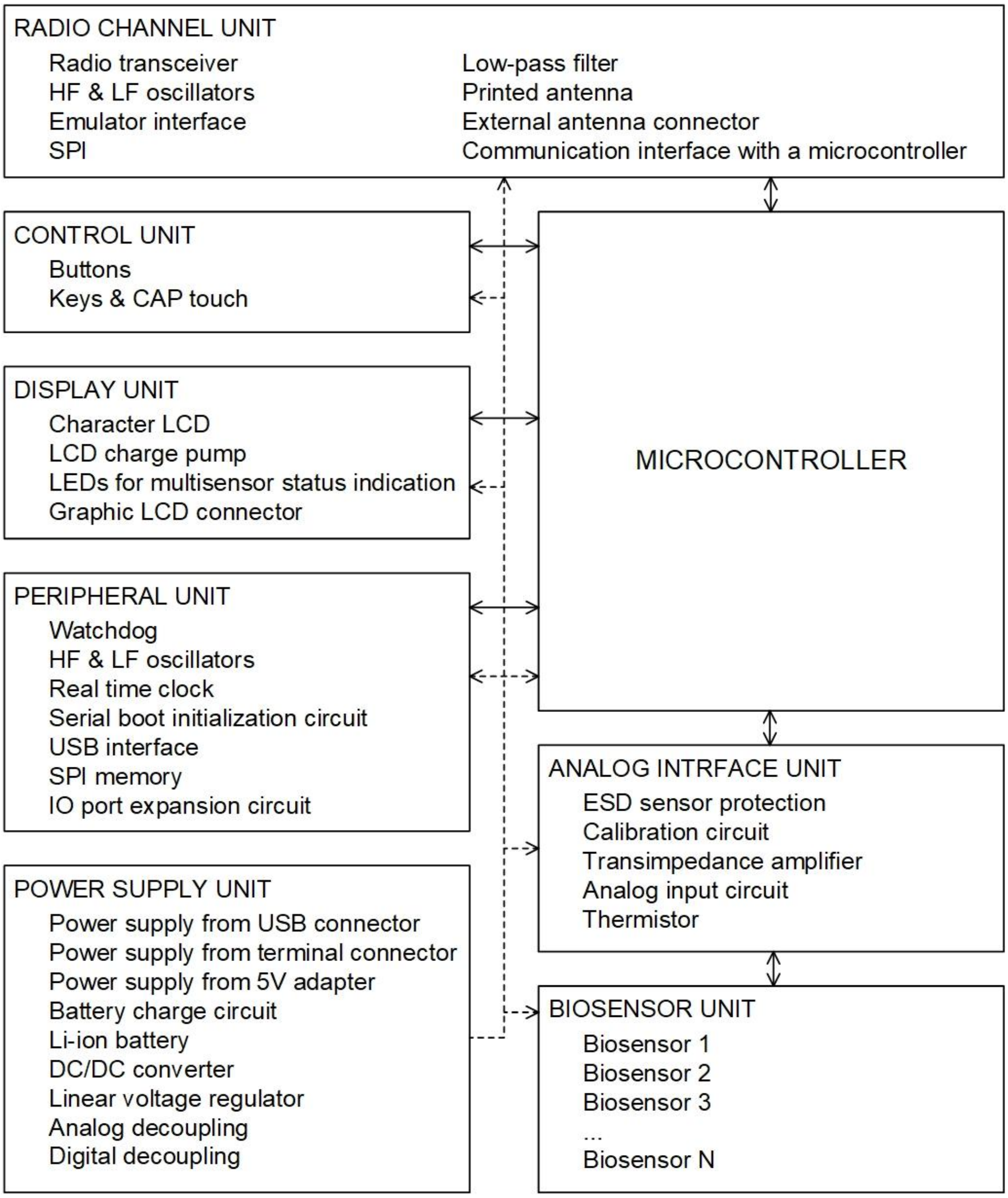

Figure 2. Multisensor functional diagram

The multisensor functional diagram in addition to the microcontroller based on the ADuCM350, contains the following units:

- The control unit that contains the keyboard or buttons, which allows to check the main functions of the multisensor both from the biosensors and the simulator offline;
- The display unit used when setting up the microcontroller or when using the multisensor as a standalone device;
- The peripheral unit that contains the necessary interfaces for the data exchange with internal and external means;
- The power supply unit that supplies all multisensor blocks with a given voltage level;
- ADuCM350 microcontroller unit;
- The analog interface unit designed to communicate with individual biosensors;
- The biosensor units;
- The radio channel unit designed to organize a wireless multisensor network.

Acting multisensor prototype

Acting multisensor prototype, which, in addition to Figure 2, includes a programmer block, is shown in Figure 3.

The created multisensor prototype was tested when working with different types of biosensors and solutions [Shkotova et al, 2016] to get recommendations for improving the scheme. The multisensor wireless channel was tested separately. In Figure 4, there is a graph of experimental results when measuring glucose concentration in a buffer solution.

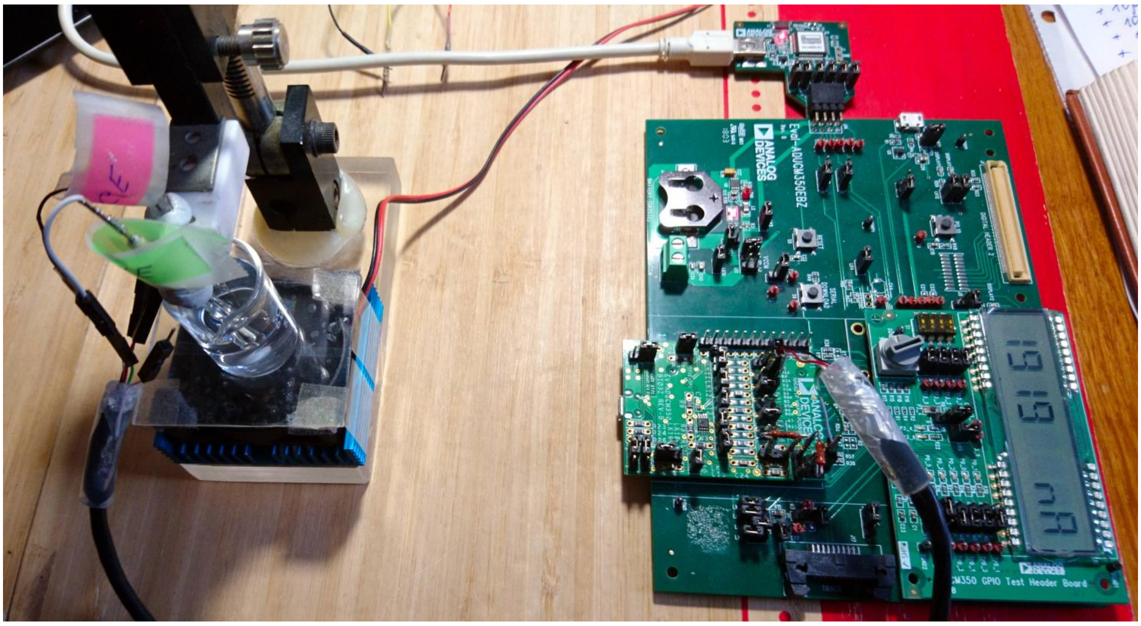

Figure 3. Acting multisensor prototype

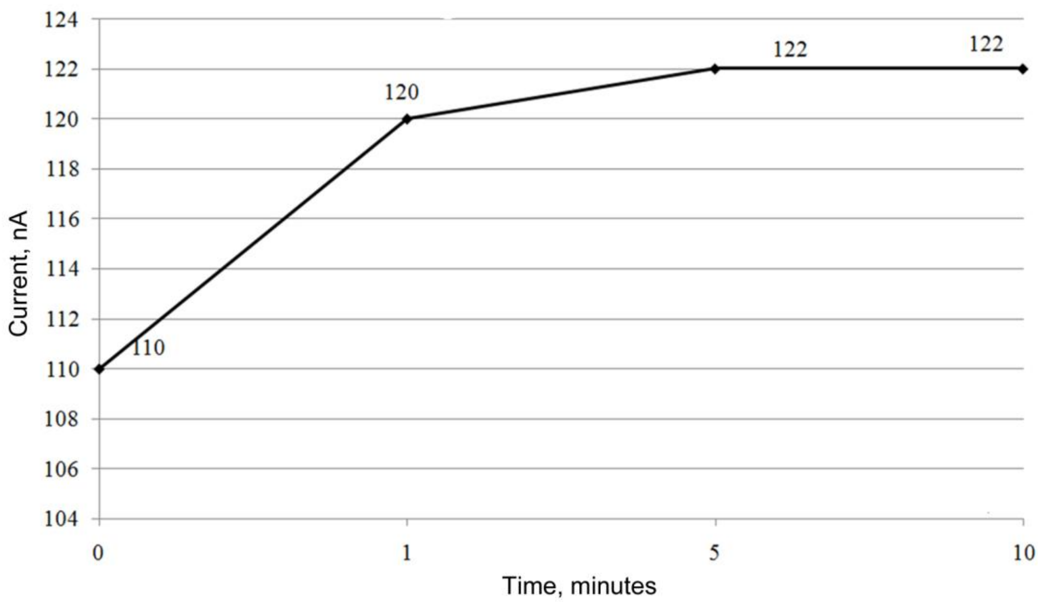

Figure 4. The results of test of measuring the 0.25 mmol of glucose in the 5 ml of buffer solution

Biosensor network

Previously, all wireless nodes of the prototype network in our development were built on the base of the wireless microcontroller JN5168 [Romanov et al, 2019]. By this structure, each node in the network, including the multisensors and the coordinator, contained a 32-bit, 32 MHz, RISC-processor and IEEE802.15.4 wireless transceiver. The network used ZigBee Pro stack as a wireless protocol for networking. The main unit for managing such network is the network coordinator. In addition, the coordinator supports the following functions: collecting, processing, visualizing and transmitting data to a workstation, Internet or cloud environment.

However, as identified by analyzing different uses of the network to evaluate the quality of different beverages, the use of the ZigBee industrial protocol limits the ability of network multisensors. This protocol requires the use of ZigBee/USB converters when using portable computers to manage the network. There are no USB ports in mobile tablets and in modern mobile phones, but at the same time these devices include standard Wi-Fi or Bluetooth wireless adapters, so the use of these ports allows replacing the coordinator in a number of applications with a tablet or mobile phone. Therefore, in the new wireless network for quality control of different beverages, it will be used not only ZigBee but also Bluetooth 5 protocol. The Bluetooth 5 protocol is focused on low power devices, which is important for the network with a battery power source. The main advantages of Bluetooth 5 (and later versions) are following: data exchange is supported at distances of up to 150 m (in open environment), which practically coincides with the capabilities of ZigBee. In industrial premises, the Bluetooth 5 range is 30-35 m. For this purpose, the Nordic Semiconductor nRF52840 (Figure 5) microcontroller was used to support the Bluetooth 5 protocol.

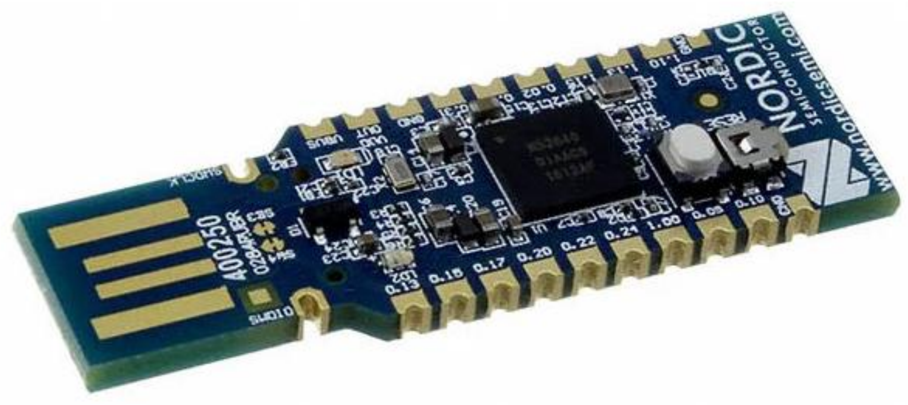

Figure 5. Wireless microcontroller nRF52840

The microcontroller nRF52840 is a multi-protocol device that supports the protocols Bluetooth 5, Thread, ZigBee, 802.15.4 and others. It is based on a 32-bit floating point ARM Cortex-M4 processor and has a clock speed of 64 MHz. Protocol switching is performed automatically without software restart. The additional use of Bluetooth has greatly expanded the capabilities of the developed multisensor. Thus, wireless multisensors can work as part of a network using ZigBee or standalone using Bluetooth protocol. In standalone mode, wireless multisensors can operate under control of mobile phone or tablet. The appearance of coordinator that supports a two-protocol sensor network is shown in Figure 6.

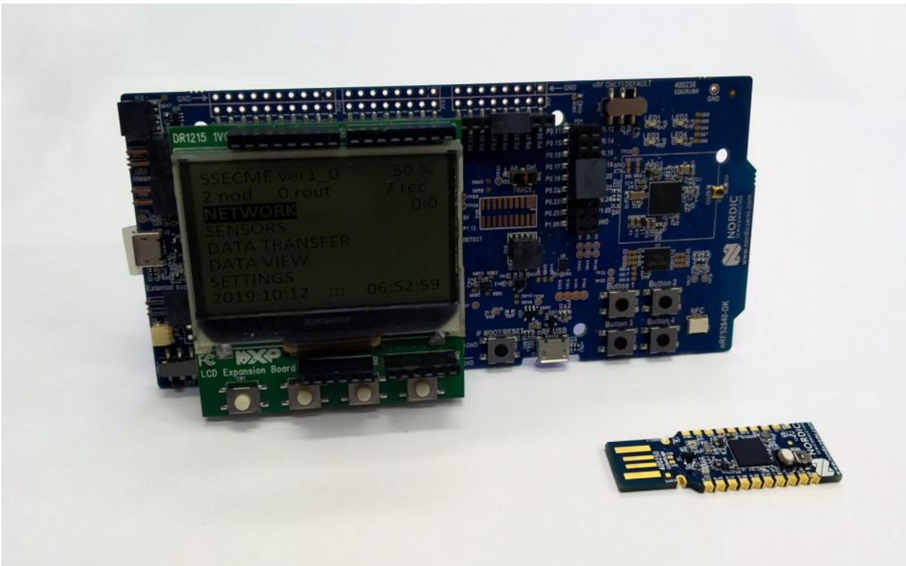

Figure 6. New coordinator (without housing) for wireless multisensor network

Conclusion

Features of circuit design solutions of multisensor module for quality control of beverage are considered. Examples of testing the concentration of glucose in solution using a prototype multisensor module are given. Features of the new network coordinator are disclosed.

Acknowledgement

The work is supported by the National Academy of Sciences of Ukraine in the frame of Scientific and Technical Program "Smart sensor devices of a new generation based on modern materials and technologies".

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