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Electronic Measurement System for IoT Sensors Studying

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ABSTRACT The paper substantiates the choice of methodology and develops an electronic measuring system that provides opportunities to study the sensors of Internet of Things systems. Based on the analysis of existing methods of building similar systems, we chose an approach and offered a method of ensuring the given level of temperature and humidity in the climate chamber. In particular, the determination of the level of relative humidity for its further regulation is carried out using a reference sensor of relative humidity and temperature. The parameters of the sensor studied by the students are determined based on the measurement of the frequency of the generator built using the NE555 chip. The necessary humidity level in the climatic chamber is maintained by mixing wet and dry air, which flows are regulated by valves of different diameters. The developed electronic measuring system was manufactured, and its experimental testing was carried out. The experimental results of the dependence of the humidity in the climate chamber, measured using the reference sensor DHT22, on the ratio of the areas of the holes in the valves indicate its nonlinearity. At the same time, the dependence of the frequency of generated oscillations and the capacity of the analog capacitive humidity sensor on the relative humidity in the climate chamber is practically linear. According to the results of the experiments we obtained an empirical formula, taken into account when programming the device and intended for further measurements of relative humidity. The main characteristics of the developed electronic measuring system are the relative humidity adjustment range (40–80 %), the temperature change range (20–80 °C), and the time to set the specified humidity level after replacing the valves (6–7 minutes). The electronic measuring system can be used for educational purposes, as well as for solving practical tasks related to the control and regulation of temperature and relative humidity of air in a closed space.

KEYWORDS sensor, humidity, digital signal processing, measuring system.

I. INTRODUCTION

The widespread application of the Internet of Things (IoT) in the practice and life of modern society has made especially acute the question of studying the physical basis of the functioning of such systems. End devices of "smart home" systems contain a variety of sensors. So, for example, the end sensor Smart Room Kona (TEKTELIC Communications, Canada) [1] contains seven different sensors. In many cases, despite the different methods of determining the measured values, the output data of such sensors are presented in digital form. This causes the use of digital sensors or digital measuring modules in their composition. Acquaintance with the principles of their operation, technical characteristics and circuit-technical approaches to use is an important stage of training specialists in the field of electronics and telecommunications. Based on this, the technical task for the device under development was formed.

The measuring system can be used in conducting scientific studies of the influence of humidity on the parameters and characteristics of small-sized objects, as well as in the educational process. Both areas of possible application provide an appropriate level of safety during its operation. In this regard, when choosing the principle of ensuring the required level of humidity, methods using, for example, the pressure of saturated steam over solutions of chemical substances were not considered [2-5]. It was in the aspect of maximum safety, reliability and simplicity of the developed device design that the analysis of literary sources was carried out. Most of the information regarding devices for creating and maintaining the humidity regime in climate chambers that meet the formulated requirements is found in patents [6-9]. The closest in design features is the device for creating and maintaining a heat-humidity regime, described by the authors [10].

Therefore, the goal of the work was to develop an electronic measuring device suitable for use in scientific research and in the educational process. In the latter case, the possibility of experimental study of the principles of implementation and functioning of digital sensors (in particular, humidity and temperature sensors) is realized.

II. ELECTRONIC MEASUREMENT SYSTEM CONSTRUCTION

The principle of operation of the developed device can be explained using the structural diagram [11] shown in Fig. 1.

The source of stable air flow 1 forms two (if possible laminar) air flows 2 directed to the heater 3. Passing through the heater, the air flows can be heated to a maximum temperature of 80°C.

The temperature of the heater is regulated using the REX-C 100 temperature controller. The use of a thermocouple as a temperature sensor, which is characterized by a small specific heat capacity, provided the ability to regulate the temperature of the heater.

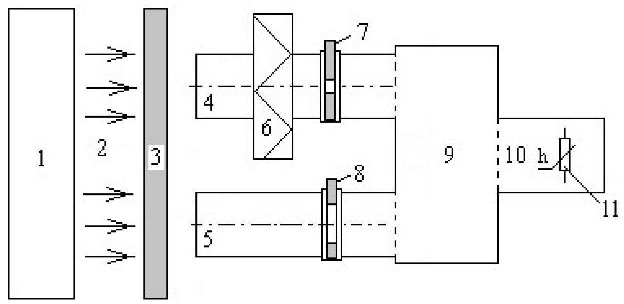

FIG. 1. Electronic measurement system for IoT sensors block diagram (1 – fan; 2 – air flows; 3 – heater; 4 – humid air channel; 5 – dry air channel; 6 – wet filter; 7 – valve of the channel of humid air; 8 – valve of the dry air channel; 9 – air mixing chamber; 10 – measuring chamber; 11 – humidity and temperature sensor).

The air stream, heated to the required temperature, is directed along air channels 4 and 5. Air humidifier 6 is placed in channel 4. The principle of operation of the humidifier is similar to the one described by the author of the patent [8], but it is structurally different from the one specified in the patent. In this case, the humidification module contains a three-dimensional structure of wet hygroscopic tapes, formed in such a way that it prevents the formation of through air flows and maximizes the area of contact of air with the moistened surface [11]. The ends of the tapes are in water, which ensures a constant level of their humidity. Thus, when passing through the humidifier 6, the air is saturated with moisture. Valves 7 and 8 are placed in the humid 4 and dry air channels 5, respectively. Depending on the diameter of the hole made in the center of the valves, the ratio between the values of the air flows at the exits of the humid 4 and dry 5 air channels changes. Both streams are fed into the mixing chamber 9. After mixing, the air flow of the resulting humidity enters the climate chamber 10. Humidity and temperature control in the climate chamber is carried out using the relative humidity and temperature sensor 11.

Two switches are placed on the front panel of the device (Fig. 2); one of them (15) turns on the power of the stand, and the second 12 - the heater. The front panel also has a thermostat 13 and a display 14 (LCD 1602) for displaying data from sensors. The display is built on the HD44780 controller and connected to the Arduino nano board using a parallel 4-bit interface.

Climate chamber 10 is made of transparent acrylic, and its side walls are printed on a 3D printer. The reference DHT22 and the investigated humidity sensor 11 are placed inside the chamber. Fig. 2 shows the case when the air duct of the dry channel is completely open (100%), and the duct of the humid channel is completely closed (0%).

Humidifier 6 is shown without the top cap. The white rectangles in the humidifier are the attached ends of the moistened hygroscopic strips. The bottom of the humidifier is filled with water. To increase the efficiency of air flow saturation with moisture in the humidifier, the direction of flow propagation is changed by 90^0.

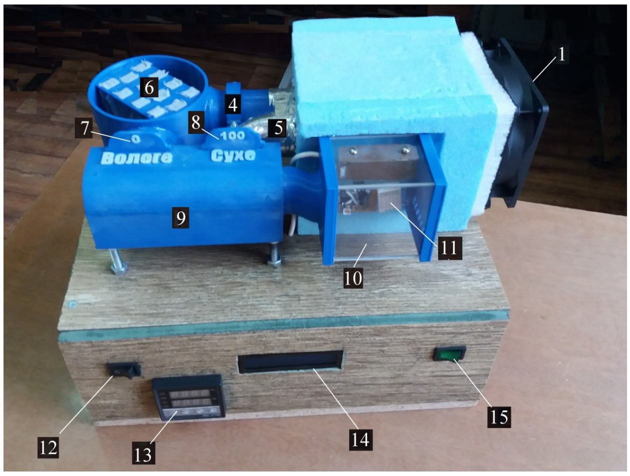

FIG. 2. Electronic measurement system for IoT sensors. Used number markers match the block diagram in Fig. 1 (1 – fan; 2 – air flows; 3 – heater; 4 – humid air channel; 5 – dry air channel; 6 – wet filter; 7 – valve of the channel of humid air; 8 – valve of the dry air channel; 9 – air mixing chamber; 10 – measuring chamber; 11 – humidity and temperature sensor; 12 – heater switch; 13 – thermostat; 14 – display, and 15 – power switch).

III. EXPERIMENTAL TESTING AND ANALYSIS OF MEASUREMENT SYSTEM CHARACTERISTICS

The parameters of the sensor under investigation are determined based on the measurement of the frequency of the generator built using the NE555 chip [12]. In calculating the capacity of a humidity-sensitive capacitor, we used an empirical formula

$$C\,[pF] = 1000 \times \frac{1865}{f\,[Hz]}, \tag{1}$$

where f is the frequency of generated oscillations (in Hz).

This expression was obtained by experiments with a capacitive sensor separated from the measuring module and used to find the capacitor capacity as a function of the frequency of the generated oscillations. Formula (1) is used in the software.

The most important experiment was studying the dependence of humidity in the climate chamber on the ratio of holes in the valves. During these studies, the total area (measured as a percentage of the duct pipe area) of the valve holes remained constant. When this condition was fulfilled, the speed of air movement in the climatic chamber also remained constant with sufficient accuracy. This made it possible to state that the pressure of the air flow on the sensor practically did not change. Fig. 3 shows the experimental results of the dependence of the humidity in the climatic chamber, measured using the DHT22 sensor, on the ratio of the areas of the holes in the valves. In the numerator of this ratio, the percentage of the area of the valve hole in the dry channel is indicated, and in the denominator, the percentage of the area of the valve opening in the humid channel is indicated, accordingly.

The minimum value of relative humidity in the climatic chamber was determined by the humidity of the room. It is possible to ensure a lower level of relative humidity by using an air dryer in the dry channel, for example, silica gel (silicon dioxide SiO_2).

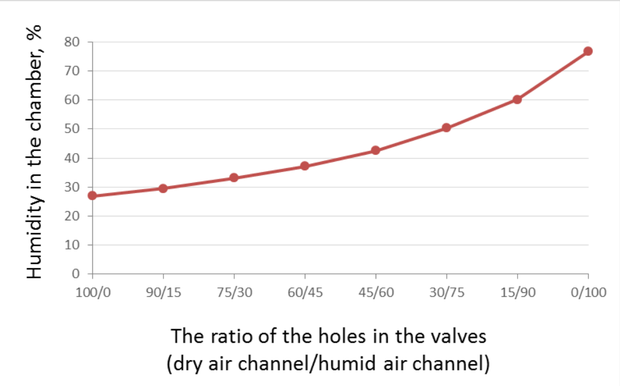

FIG. 3. Dependence of humidity in the chamber on the ratio of holes in the valves.

Fig. 4 shows the experimental dependence of the frequency of the generated oscillations on the humidity in the climate chamber.

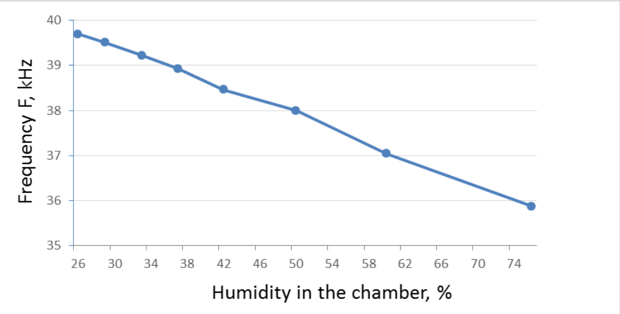

FIG. 4. Dependence of the frequency of generated oscillations on humidity.

Fig. 5 shows the dependence of the capacity of the analog capacitive humidity sensor on the relative humidity in the climatic chamber. It should be noted that the value of the capacity depends almost linearly on the relative humidity.

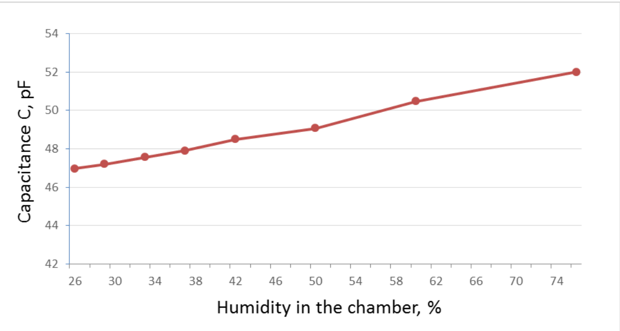

FIG. 5. Dependence of the capacitor capacity on the humidity in the chamber.

The deviation from linearity (Fig. 5) at a relative humidity of 50%, as well as the deviation from the linear dependence of the frequency of the generated oscillations on the relative humidity, should be considered random. Most likely, such a deviation could be caused by interference. Further research will provide an opportunity to find out the reason for obtaining such a result.

At a fixed temperature of the heater, the air temperature in the climate chamber changed when the ratio of the valve holes changed (Fig. 6). This fact should

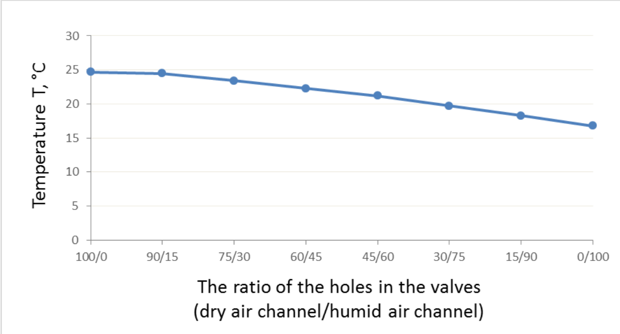

FIG. 6. Dependence of the temperature in the chamber on the ratio of holes in the valves.

be taken into account when conducting experiments to study the influence of humidity on the parameters of certain objects.

To a large extent, the effect of lowering the temperature in the climatic chamber can be explained by increasing the proportion of air with increased humidity. The initial air temperature in both channels was the same, but the process of air saturation with moisture in the humid channel was accompanied by a decrease in temperature.

IV. CONCLUSION

The paper substantiates the choice of the humidity measurement method and the type of sensors that should be used in the developed device. The measurement system was designed and manufactured.

The range of changes in relative humidity is from 40% to 80%, and the range of temperature changes is from 20°C to 80 °C.

The time to establish the required level of humidity after replacing the valves was 6–7 minutes. After the completion of the transient processes, the deviation of the relative humidity value was within the error of the DHT22 digital sensor humidity measurement, i.e. ± 2%.

Analysis of developed device characteristics confirmed the linearity of the sensor capacity dependence on the humidity in the climatic chamber and allowed us to obtain an empirical formula taken into account in the programming of the device.

The developed electronic measuring system can be used both in the educational process and for scientific research that requires regulation of air humidity in a closed space.

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AUTHOR CONTRIBUTIONS

V.B. – conceptualization, methodology, writing and reviewing drafts of the article, approving the final draft; B.F. – development and manufacture of devices, software, performing the experiments, preparing figures; H.L. – investigation, writing-review, and editing; M.R. – investigation, writing-original draft preparation, writing-review and editing.

COMPETING INTERESTS

The authors declare no conflict of interest.

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Електронна вимірювальна система для вивчення сенсорів IoT

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АНОТАЦІЯ В роботі обґрунтовано вибір методики і розроблено електронну вимірювальну систему, що надає можливості вивчати сенсори систем Інтернету речей. На основі аналізу існуючих методів побудови аналогічних систем обрано підхід та запропоновано методику забезпечення заданого рівня температури і вологості у кліматичній камері. Зокрема, визначення рівня відносної вологості для його подальшого регулювання здійснюється за допомогою еталонного давача відносної вологості та температури. Параметри досліджуваного студентами сенсора визначаються на основі вимірювання частоти генератора, реалізованого на мікросхемі NE555. Необхідний рівень вологості у кліматичній камері підтримується шляхом змішування вологого та сухого повітря, потоки яких регулюються засувками різного діаметра. Розроблена електронна вимірювальна система виготовлена, проведене її експериментальне випробування. Експериментальні результати залежності вологості у кліматичній камері, виміряні за допомогою еталонного сенсора DHT22, від співвідношення площ отворів у засувках свідчать про її нелінійність. Водночас залежність частоти генерованих коливань та ємності аналогового ємнісного давача вологості від відносної вологості у кліматичній камері є практично лінійною. За результатами експериментів отримане емпіричне співвідношення, враховане під час програмування пристрою і призначене для проведення подальших вимірювань відносної вологості. Основні характеристики розробленої електронної вимірювальної системи: діапазон регулювання відносної вологості – 40-80%, діапазон зміни температури – 20-80 °C, час встановлення заданого рівня вологості після заміни засувок – 6-7 хв. Електронна вимірювальна система може застосовуватись для навчальних цілей, а також для розв'язання практичних завдань щодо контролю та регулювання температури і відносної вологості повітря у замкненому просторі.

КЛЮЧОВІ СЛОВА сенсор, вологість, цифрове оброблення сигналів, вимірювальна система.

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