Remote Temperature and Humidity Measurement System

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***Abstract*—** The relevance of the study lies in high-quality remote measurement of temperature and humidity in compliance with the requirements for the safety of transmitted data.

The purpose of this study is to measure temperature using indirect features, i.e. the difference in the speed of sound for agriculture and industry.

The studywas made on 20 pages of printed text, contains 1 drawing and a list of references, which consists of 10 sources. The study was done in English

***Keywords*—**temperature measurement, humidity measurement, the speed of sound, the remote measurement.

I. Introduction

The main directions of our state's policy in the field of environmental protection and use of natural resources include the creation of conditions for the environmentally safe existence of the environment. The main criteria for environmental conditions are atmospheric pressure, humidity, and temperature. There are weather stations around the world that regularly measure temperature and humidity in order to detect changes in a timely manner, assess, prevent and eliminate the consequences of negative processes.

Unfortunately, the accuracy of temperature measurement by weather stations cannot be 100% accurate. This is affected by direct sunlight, precipitation, and other weather conditions. Also, weather stations make measurements only at a certain point and because of this, a large number of them are required. Our offer allows you to make accurate measurements of temperature and humidity in all the necessary space from any point.

The relevance of the study, in connection with the above, consists in high-quality remote measurement of temperature and humidity in compliance with the requirements for the safety of transmitted data. To know exactly what to measure, you need to have knowledge about the temperature measurement process and its main characteristics.

Air temperature describes the thermal state of the atmosphere and is measured in degrees Celsius (°C) and Kelvin (K). It determines the conditions of formation and the nature of the weather depends on the angle of incidence of sunlight. The temperature is affected by the transparency of the atmosphere, cloud cover, wind direction, precipitation, and the like. The difference between the highest and lowest air temperatures is called the amplitude of temperature fluctuations.

To study the weather, it is necessary to observe all its elements: air pressure, temperature, humidity, cloud cover, wind direction and its strength. Weather observations are made at weather stations using special devices.

However, all of the weather stations have the same drawback – measurement of temperature and humidity. Currently, it is important to measure the temperature on the field area. This problem is solved by increasing the measurement points followed by averaging.

We proposed to measure the average temperature and humidity by measuring the difference in the speed of sound.

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II. Analytical Review of the Sources

Agricultural production depends mostly on the weather and climate. In General, the possibility of growing certain types of crops is determined by the necessary amount of heat and light, and their yield is determined by the amount of precipitation and moisture reserves in the soil. [9]

In our country, about 70 % of the areas occupied by agricultural crops are located in areas of insufficient and unstable moisture. The choice of optimal sowing dates, the feasibility and timing of applying mineral fertilizers, carrying out various agrotechnical and reclamation activities-all of the above mentioned is determined by meteorological conditions. Conditions for sowing, tillage, and harvesting determine the productivity of agricultural machines and ultimately affect crop yields.

Temperature and humidity monitoring data are used to warn about adverse weather events for the national economy, to study the climate and its changes, as well as to directly provide information about the weather to service organizations.

We can assign a number (with dimension) to each body that characterizes the temperature of this body, and the higher the temperature, the greater the number.

To do this, you need to select a temperature standard, that is, a body that under certain conditions, equilibrium and fairly easy to reproduce, would have a certain temperature number. This temperature number is the reference point of the corresponding temperature scale – an ordered sequence of temperature numbers that allow you to quantify the temperature of a particular body. [1]

The temperature scale allows you to indirectly measure the body temperature by directly determining a physical parameter that depends on the temperature.

The most famous example of a temperature reference is water. The melting and boiling points of water at normal atmospheric pressure are selected as reference points in modern (but not necessarily native) temperature scales proposed by Anders Celsius (1701-1744), Rene Antoine fershaw Reaumur (1683 – 1757), and Daniel Gabriel Fahrenheit (1686 – 1736). The latter created the first practically usable alcohol and mercury thermometers, widely used until now.

Reomur and Fahrenheit temperature scales are currently used in the United States, great Britain, and some other countries.Introduced in 1742, the temperature scale of Celsius, which proposed a temperature interval between the temperatures of ice melting and water boiling at normal pressure (101325 PA) divided into one hundred equal parts (degrees Celsius), is widely used today, although in a refined form, when 1°C is equal to 1 K. The boiling point of water becomes approximately equal to 99.975 ° C. These corrections are usually not significant, since most used alcohol, mercury, and electronic thermometers do not possess (since this is not necessary) high enough accuracy to take them into account.

After the introduction of the International system of units (SI), two temperature scales are recommended for use. The first scale is thermodynamic, which does not depend on the type of thermometric substance and is introduced using the Carnot cycle. [7] the unit of temperature measurement in this temperature scale is 1 Kelvin (1 K), one of the seven basic units in the SI system. This unit is named after Lord Kelvin (W. Thompson), who developed this scale and kept the value of the temperature unit the same as in the Celsius temperature scale. The second recommended temperature scale is the international practical one. [8] This scale has 11 reference points – the temperatures of phase transitions of a number of pure substances, and the values of these temperature points are constantly updated. The unit of temperature measurement in the international practical scale is also 1 K.

In addition to setting reference points that are determined using the temperature standard, you must select a thermodynamic property of the substance that depends on the temperature (a sign of temperature), which should be easily reproduced. This allows you to get a set of temperature points that are intermediate with respect to the rapper points.

For the numerical characteristic of temperature, you must select a sign of temperature change (thermometric property-a physical property of a substance that depends on temperature), which is also easily reproduced, which allows you to get an ordered set of temperature numbers.

Such signs are, for example: the change in volume during heating, a change in the electrical resistance of bodies, the occurrence of an electric current in bodies, etc. Corresponding to these signs, temperature measuring devices (thermometers) will be: gas and mercury thermometers, thermal resistance, thermocouple.

By bringing the thermometer into a state of thermal equilibrium with the body whose temperature is to be measured, it can be stated on the basis of the zero beginning of thermodynamics that their temperatures are equal. This allows you to assign the body the same temperature number (temperature value) that the thermometer has. Another method of measuring temperature is implemented in pyrometers-devices for measuring the temperature of bodies by the intensity of their thermal radiation. In this case, the equilibrium state of the thermodynamic system is reached, from the pyrometer itself and the thermal radiation received by it. More information about this will be provided in the section of the course devoted to the quantum properties of equilibrium thermal radiation. Now we only note that optical pyrometry (non-contact temperature measurement methods) is used in metallurgy to measure the temperature of the melt and rolled products, in laboratory and production processes where it is necessary to measure the temperature of heated gases, as well as in plasma studies.

Constant volume gas thermometer: a thermometric body is a portion of gas enclosed in a balloon with a process. The basis for measuring temperature (thermometric sign – - gas pressure at a certain fixed volume. The constancy of the volume is achieved by moving the right tube level in the left tube of the pressure gauge is brought to the same level (reference mark) and at this point, measurements are made of the difference in the height of the liquid levels in the pressure gauge. Taking into account various corrections (for example, thermal expansion of glass parts of the thermometer, gas adsorption, etc.) allows you to achieve the accuracy of measuring the temperature of a gas thermometer with a constant volume equal to one thousandth of a Kelvin.

Gas thermometers have the advantage that the temperature determined with their help at low gas densities does not depend on the nature of the gas used in a wide range, and the scale of the gas thermometer-well coincides with the absolute temperature scale (it will be written below). In the second Chapter, we will describe in more detail the ideal gas thermometer that determines the absolute temperature scale.

Gas thermometers are used for calibration of other types of thermometers, such as liquid thermometers. They are more convenient in practice, however, the scale of the liquid thermometer, which is graded according to the gas one, is usually uneven.

A liquid thermometer is the most commonly used thermometer in everyday life, based on changes in the volume of a liquid when its temperature changes. In a mercury-glass thermometer, the thermometric body is a glass balloon with a capillary and mercury placed in it. A thermometric feature is the distance from the mercury meniscus in the capillary to an arbitrary fixed point. Mercury thermometers are used in the temperature range from – 39 ° C to several hundred degrees Celsius. At high temperatures (more than 300 ° C), nitrogen is pumped into the capillary (pressure up to 100 ATM or 107 PA) to prevent the mercury from boiling. By adding a waist, the lower temperature measured by a mercury thermometer can be reduced to – 59 ° C.

Other types of widely used liquid thermometers are alcohol (from – 110 ° C to + 50 ° C) and pentane (from – 200 ° C to + 20 ° C). Note that water can not be used as a thermometric body in a liquid thermometer: the volume of water with an increase in temperature first falls, and then increases, which makes it impossible to use the volume of water as a thermometric feature.

However, due to the development of measuring technology, the most convenient technical types of thermometers are those in which the thermometric feature is an electric signal. These are thermal resistances (metal and semiconductor) and thermocouples.

Metal resistance thermometer: the temperature measurement is based on the phenomenon of metal resistance increasing with temperature. For most metals near room temperature, this dependence is close to linear, and the temperature coefficient of resistance for pure metals has a value close to 4.10-31 / ° C. the Thermometric characteristic is the electrical resistance of a thermometric body – a metal wire. Most often, platinum wire is used, as well as copper wire or their various alloys. The range of application of such thermometers is from hydrogen temperatures (~ 20 K) to hundreds of degrees Celsius. At low temperatures in metal thermometers, the dependence of resistance on temperature becomes significantly nonlinear and the thermometer requires careful calibration.

Semiconductor resistance thermometer (thermistor): temperature measurement is based on the phenomenon of reducing the resistance of semiconductors with increasing temperature. Since the temperature coefficient of resistance of semiconductors in absolute value can significantly exceed the corresponding coefficient of metals, the sensitivity of such thermometers can significantly exceed the sensitivity of metal thermometers.

Specially manufactured semiconductor thermal resistances can be used at low (helium) temperatures. However, it should be noted that in conventional semiconductor supports, defects occur due to the influence of low temperatures, which leads to a lack of reproducibility of the measurement results. Most often, germanium and carbon (coal) are used as the material for the thermistor.

A thermocouple is a junction of two metal wires at a measured temperature and the other two ends of these wires at a known temperature. The resulting closed electric circuit includes a measuring device. The electromotive force (thermo-EMF) that occurs in such a circle depends on the temperature difference between the two junctions – the measuring and the free one. Thus, the thermometric body is a junction of two metals, and the thermometric sign occurs in the thermo-EMF chain. The sensitivity of thermocouples ranges from units to hundreds of mV / K, and the range of measured temperatures from nitrogen to one and a half thousand degrees Celsius (for noble metal thermocouples). Greatest use is made of thermocouples: copper-constantan, chromel-alumel, platinum-rhodium, iridium-rhodium.

It should be noted that the thermocouple can only measure the temperature difference between the measuring and free welding. The free junction is usually possible innormal room temperature. Therefore, to measure the temperature with a thermocouple, you must use an additional thermometer to determine the room temperature or a system to compensate changes in the temperature of the free junction. [2]

In the radio often apply the concept of noise temperature equal to the temperature to which must be heated resistor, consistent with an input resistance of electronic devices to the capacity of the thermal noise of this device and resistor was equal to a certain frequency band. The possibility of introducing such a concept is due to the proportionality of the average noise power (the average square of the noise voltage on the electrical resistance) to the absolute temperature of the resistance. This allows you to use the noise voltage as a thermometric indicator for measuring temperature. Noise thermometers are used to measure low temperatures (below a few Kelvins), and in radio astronomy to measure the radiation temperature of space objects.

Measurement error is a value that characterizes the deviation of the measured physical quantity from its actual (true) value. The actual (true) value of the measured physical quantity is the value obtained using an exemplary (reference) device. [3]

When you repeatedly measure a value, it is easy to make sure that the measurement result changes all the time, that is, in each case, there is a deviation of the measurement result from the average value of the measured value. In addition, taking measurements of the same value in a different time interval gives not only other deviations from the average value, but also a different average value of the measured value.This is due to the fact that the measured physical quantity of the body under study, as well as the measure used, changes during the measurement time. These changes are caused by the influence of external factors: changes in ambient temperature, atmospheric pressure, air humidity, room vibration, electrostatic charges, stray currents, and so on. So, it is not possible to accurately determine the measured value, that is, without the appearance of any deviations during multiple measurements.

As a result of a large number of random and deterministic factors that occur during the manufacture, storage and operation of measuring instruments, the nominal values of measures and readings of measuring instruments differ from the true values of the measured values. These deviations characterize the errors of the measuring tools.

The practical usefulness of any measurement is determined by indicating its error, that is, the quantitative characteristic of the deviation of the measurement result from the true value of the measured physical quantity. The occurrence of measurement errors is due to the influence of various physical factors that accompany the measurement.

The traditional analytical approach to determining errors is to divide them into components, each of which is determined by certain factors. This allows us to investigate the sources of the error components, conduct the necessary experiments, including auxiliary measurements, and, as a result, determine the properties of the error and evaluate its components with the necessary accuracy. Knowing the properties and estimates of the components, you can correctly take them into account when evaluating the total error, and if necessary, enter an amendment to the measurement result and (or) organize a measurement experiment so that the individual components, and with them the total error, are reduced to an acceptable value. To improve the objectivity of the assessment of measurement errors and determine ways to reduce them, in order to improve the quality of measurements, it is necessary to know the sources (causes) of the various components of the total measurement error and the patterns of their change.

Mercury or alcohol thermometers are used to measure air temperature under normal conditions. When measuring temperatures above 00C, you should use mercury thermometers, because mercury expands evenly when heated, and alcohol-unevenly. At temperatures below 00C, mercury thickens, so it is recommended to use alcohol thermometers.

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To measure humidity, psychrometers are used, which consist of two mercury thermometers: dry and wet. The reservoir of the wet thermometer is wrapped in gauze or other hygroscopic cloth, the end of which is lowered into the water. Due to the evaporation of moisture, the temperature on the wet thermometer decreases. The difference in the readings of wet and dry thermometers is greater, the lower the relative humidity and is due to the removal of heat from the wet thermometer due to moisture evaporation. Only when the relative humidity is 100%, the thermometer readings are the same.[4]

Cause of errors: imperfection of traditional measurement methods.

III. Object, Subject and Research Methods

The object of the study is the development of a measuring device.

The subject of the study is a method for measuring temperature and humidity without using weather stations.

The novelty of the study consists in creating a software and hardware complex that allows you to obtain data using indirect measurements; determining the accuracy of the information received from the monitoring system and checking the reliability of the data; developing a device that uses sensors to capture the data necessary for monitoring.

Currently, it is important to measure the temperature on the field area. This problem is solved by increasing the measurement points followed by averaging. We proposed to measure the average temperature and humidity by measuring the difference in the speed of sound [11].

Statistical quality analysis requires obtaining various correlation characteristics. These characteristics include mutual, partial, and multiple correlation coefficients. [5]

The mutual correlation coefficient rxy of random variables x and y that acquire values x = {x1, x2,..., xn}, y = {y1, y2, ..., ym}, where in General n = m ≥ 100 values, is called the mathematical expectation of the product of standardized (normalized) deviations of random variables:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - mx) * (y_i - my)}{\sqrt{\sum_{i=1}^{n}(x_i - mx)^2 * (y_i - my)^2}} \tag{1}$$

where mx and my are mathematical expectations. The rxy characteristic is dimensionless.

For a system of random variables {X1, X2, ..., Xn} get a normalized matrix of mutual correlation coefficients of the form:

$$\|r_{ij}\| = \begin{Vmatrix} 1 & r_{12} & r_{13} & \cdots & r_{1n} \\ r_{21} & 1 & r_{23} & \cdots & r_{2n} \\ r_{31} & r_{32} & 1 & \cdots & r_{3n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & r_{n3} & \cdots & 1 \end{Vmatrix}. \tag{2}$$

The mutual correlation coefficient characterizes the tightness of the linear relationship between random variables and has the following properties:

1) change Limits 1 ≤ rxy ≤ +1.

2) the Equality |rxy| =1 indicates a functional relationship between the random variables X and y. the Converse is incorrect: in a nonlinear functional relationship, the correlation coefficient may be less than one and even equal to zero.

3) If the random variables X and Y are independent, then rxy = 0. The opposite is not true: for rxy = 0, random variables can be either independent or dependent. If rxy = 0, random variables are called incoherent or uncorrelated.

4) the rxy > 0 Inequality indicates a positive correlation between the random variables X and Y: when one of them increases, the other tends to increase on average. At rxy < 0, a negative correlation is indicated: when one of the random variables increases, the other tends to decrease on average.

The multiple correlation coefficient is used to describe a system of random variables {X1, X2, X3, ..., Xn}. It is a characteristic of the correlation between the value X1, on the one hand,

and the entire set of values {X1, X2, X3, ..., Xn} with another. [6] Numerical values of this coefficient, which is also called the summary correlation coefficient X1 and {X2, X3, ..., Xn}, found by the formula:

$$r_{x_1 (x_2, x_3,...,x_n)}=\sqrt{1-P/P_{11}} \quad (3)$$

where P=det (rij) is the determinant of the square matrix of mutual correlation coefficients; P11 is the minor of this determinant (obtained by crossing out 1 row and 1 column).

The significance of the coefficients is checked using a system of values of gradations of tightness of connection:

0 < / r|<0.2 – very weak
0 < / r|<0.4-weak
0 < / r|<0.7-average
0 < / r|<0.9-strong
0 < / r|<1.0 – very strong

Small values of coefficients suggest that one or more random variables that are analyzed are uninformative and can be deduced from further consideration. In addition, according to the third property of the multiple correlation coefficient, the original matrix of cross-correlation coefficients can be simplified by deleting one or more rows.

Since this paper studies the propagation of sound waves in the air, we will focus in more detail on issues related to the speed of sound. The velocity of the longitudinal wave propagation in an elastic medium is expressed by the formula:

$$\upsilon = \sqrt{\frac{E}{\rho}}, \quad (4)$$

Where E is the volume elasticity modulus of the medium or the inverse of the compressibility of the medium:

$$\frac{V - V_0}{V_0} = -kF; \quad k = \frac{1}{E}. \quad (5)$$

For the propagation velocity of small perturbations in a gas, in particular for the speed of sound, the ratio is valid

$$\upsilon = \sqrt{\frac{dp}{d\rho}}. \quad (6)$$

A.

If the process of sound propagation is considered adiabatic, then

$$pV^{\gamma} = C; \quad p = C\rho^{\gamma}. \quad (7)$$

Then

$$\frac{dp}{d\rho} = \gamma c \quad \rho^{\gamma-1} = \gamma\frac{p}{\rho}. \quad (8)$$

Substitute (8) in (4) and get

$$\upsilon = \sqrt{\gamma\frac{p}{\rho}}. \quad (9)$$

Using the Clapeyron formula, we rewrite (9) as

$$\upsilon = \sqrt{\gamma \frac{RT}{\mu}} \tag{10}$$

For air

$$V = 20{,}1\sqrt{T}\ , \tag{11}$$

That is, the speed of sound is proportional to the square root of the absolute temperature.

IV. Resylts of the Study

We decided to develop software for firmware of the Arduino Uno R3 Board using specialized Arduino software.

The collected information is displayed on the built-in display (Fig. 1), after which it is written to the repositories and sent to the server for post-processing and archiving. The data obtained using a special program is presented in the form of graphs and forecasts for their changes based on the analysis of tracking dynamics.

Fig. 1 The device to be monitored (top view)

Components used for creating a monitoring device:

- Arduino UNO R3 - 1 PC.
- Layout Board – 2 PCs.
- Ethernet shield w5100 - 1 PC.
- MQ-2 gas sensor-1pc.
- Humidity/temperature sensor DHT-22-1pc.
- Pressure/temperature sensor BMP-180-1pc.
- LDR light sensor-1pc.
- Soil moisture sensor FC-28 - 1 PC.
- Real time clock Tiny RTC V1. 1-1 piece.
- 4x40 display-1pc.
- Power module-1 piece.
- LEDs – 5 PCs.
- Shift register-74HC595 - 1 PC.
- Capacitors
- Resistors

When transmitting received data from sensors to a remote server, there may be a situation where the information may become corrupted or not be transmitted at all.

This can happen for several reasons:

- the cable is damaged in some place;
- there was a data transfer conflict.

When transmitting data over a long distance via a cable, it should be taken into account that it must pass in a place that is difficult to reach for an ordinary person or animal (on poles or under the ground). It is also worth taking into account the weather conditions and the state of the environment where the cable will pass. First of all, it must be shielded so that external electronic fields cannot distort the original signal. Second, it must be very well insulated (protected by a plastic shell). Third, it does not often bend over 90 degrees. Due to frequent and severe bends in the cable may be damaged. And even if this is not visible from the outside, it does not mean that the conductors are not broken off inside.

If the connection between the client (device with sensors) and the server is made using a wifi connection, it is reasonable to encrypt the data to protect it from interception. You can use one of the most common algorithms – WPA2.

WPA2 uses a stronger AES encryption algorithm, which is very difficult to break, but not impossible. The wireless network transmission rate is reduced when WPA2-PSK (AES) is enabled, because encryption and decryption take some time. This encryption algorithm is not ideal, but it is the best choice for this case. If you use a more powerful encryption algorithm, it can significantly slow down the monitoring process.

CONCLUSION

As a result of this work, we developed software that allows us to determine the accuracy of the information received from the monitoring system and check the reliability of the data. The developed software meets the requirements set in the terms of reference.

Created software performs the following functions:

- Processing a differential signal;
- Determination of the reliability of the received data;
- Storing data on external files.

The software fully meets the requirements for organizing input and output data, reliability requirements, and other requirements specified in the terms of reference

Working with the software is carried out using a convenient interface, and is designed to work in a dialogue mode with a user who is not a programmer.

The developed software takes up 617 KB of disk space (only *.exe file). The maximum size of the product together with log files can reach several gigabytes (when using the program for more than a year).

The following set of hardware and software tools with minimal parameters is recommended for software operation:

- Intel Pentium IV processor 1 GHz or later;
- RAM: from 512 MB;
- minimum disk space of 10 GB;
- screen with a resolution of at least 800x600 pixels;
- OS: Windows XP and higher.

Description of the equipment used

The device is based on the Arduino Uno R3 controller with an ATmega 328 chip and an extension for working with the network. The necessary environmental parameters are collected by reading data from humidity, temperature, atmospheric pressure, illumination, and precipitation sensors.

The system has several humidity sensors: atmospheric – installed on the surface; ground-directly into the ground. Thermosensors are placed on a similar principle, the air temperature sensor can be placed next to the humidity sensor and barometer, and the sealed thermocouple can be placed in the ground. The light sensor is installed at a distance from objects that may interfere with direct sunlight falling on the sensor. The precipitation detector is located in the open air for timely response during precipitation in the form of rain or snow. The sensor also responds to dew, which may appear early in the morning on the device.

The paper defines the basic principles of measuring air temperature and humidity; a device has been developed that takes the necessary data and transmits it to the server.

The following tasks were solved:

- analysis of the process of measuring air temperature and humidity;
- the main research directions are defined;
- a device has been developed that uses sensors to capture the necessary data for monitoring;
- analyzed and defined methods for protecting data transmitted from the device to the server.

With the help of the developed device, you can accurately and correctly remove such indicators: temperature, humidity. It is made of sensors that transmit data to a small screen. This data can also be transmitted remotely. The cable connection between the device and the server must be well protected from external stimuli and collisions. The wireless connection will be encrypted using the WPA2 encryption algorithm.

The implementation was completed and showed full functionality of the proposed method.

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