Development and Research of a Portable Distance Measuring Device

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Abstract— **The basic steps of developing a microprocessor ultrasonic device for measuring the distance to the object are shown. The structure of the device proposed. Results of the research of work of the developed device for the possibility of its use are presented and analyzed.**

Keywords— distance, ultrasound, microprocessor device, device parameters

I. INTRODUCTION

The speed of sound is the speed at which acoustic waves widening in a resilient environment. Wave dissemination is related to the oscillatory motion of the particles of the medium, in which the direction of dissemination of the wave and the direction of motion of the particles of the medium may not coincide.

Distance measurement is an important and widespread process in today's operating environment of various industries, construction and at home. Obtaining adequate results of measured distances and the ease of use of devices for determining distances are of paramount importance. Existing distance measurement systems cannot sufficiently fulfill the tasks set out and be used by the general public. Therefore, improving the performance of accessible distance measurement and development systems is an important task. [1] The distance meter must have high metrological characteristics, including high positioning accuracy, and also be accessible to a wide range of users.

II. THE PURPOSE OF THE ARTICLE

Development of the portable measuring system and analysis of the possibilities of its use.

III. MAIN MATERIAL

The measuring system consists of an ultrasonic module, a microprocessor board based on the STM32F103 microcontroller and an OLED SSD1306 display to display the measured information.

The ultrasonic module is designed to determine the distance from the emitter to the obstacle and works as follows. The module generates a pulse that triggers an ultrasonic wave and measures the value of the echo.

$$l = \frac{ts}{2},$$

where l - distance to the obstacle;

s - speed of sound;

t – the time at which the impulse overcomes the path from the emitter to the obstacle and back.

The JSN-SR04T ultrasonic module was used in the research. The module has a working voltage of 5 *V*. The range of technical ability to determine the distance from 2 to 600 *cm*. The module is not affected by solar radiation and electromagnetic noise. The module is equipped with 4 pins for connection to the circuit. Two of them are designed for power connection: Vcc and Gnd; an input pulse is applied to the Trig input, and a signal whose duration is proportional to the measured distance is removed from the Echo output [2].

The principle of the module is that when the input to the positive pulse on the transmitter is formed by pulses with a frequency of 40 *kHz* and the receiver expects a reflected wave signal. Upon receipt of the reflected signal to the receiver is the formation at the output of the pulse module. The impulse is transmitted to the controller.

In order to investigate the characteristics of the distance measuring device, a block diagram of the experimental setup was developed, which includes: microprocessor processing board, display for displaying measured information, battery, directly ultrasonic module and personal computer (not shown) for code generation and its debugging (Fig. 1).

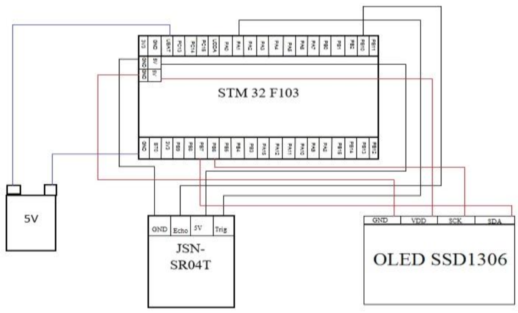

Figure 1. Structural diagram of the device for measuring distance

After assembly of the device on the basis of the given block diagram and checking it, a block diagram of the algorithm of functioning of the future device was developed (Fig. 2).

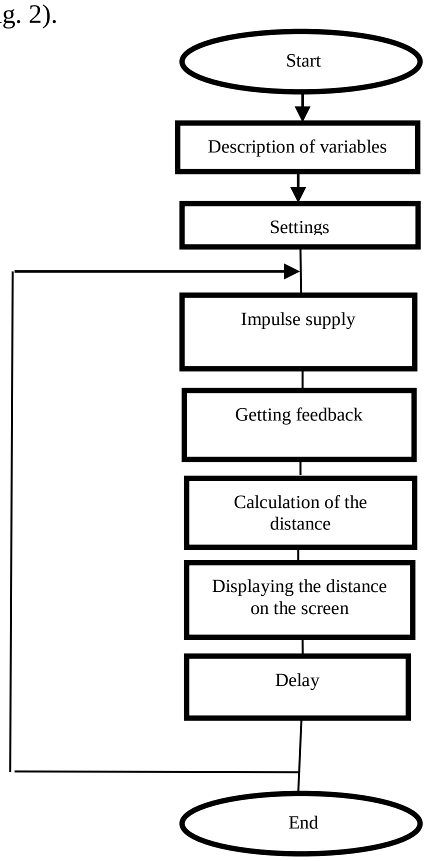

Figure 2. Flowchart of the algorithm

Description of the algorithm:
- Connecting required libraries and defining variable names.
- Description of the used variables.
- Adjust the serial port speed, input and output peaks.
- Creating an ultrasonic wave signal.
- Receive feedback in the form of the duration of the ultrasonic wave to the obstacle and back.
- Obtaining the motion time to the obstacle by dividing the duration of the ultrasonic wave to the obstacle and back in half.
- Determining the distance by the formula.
- Get and display the distance on the screen.
- Organization of closed measurement cycle.
- Repeat cycle.

The speed of widening of sound waves depends on the elastic properties, temperature and density of the medium. It is expedient to examine the developed measuring system in terms of the possibilities of its further use. In particular, it is necessary to check the accuracy of determining the distance with the help of the developed device in the whole range of the module (20… 600 *cm*), as well as the possibility of using the meter for different materials and at different angles of mutual placement of the emitter and obstacles.

For further experiments, a module fixed so that the wave moves horizontally. On the path of the wave motion consistently at different distances were established obstacles, which reflected the sound wave. The distance from the emitter to the obstacle is determined by the ruler with millimeter divisions.

The obtained distance values for the developed device were compared with the ruler readings. The absolute error is defined as the difference between the measured and the true distance, and the relative one is determined by the formula:

$$\varepsilon = \frac{\Delta a}{a} \cdot 100\% ,$$

where a — value of the variable, the result of measurements;
Δa — absolute measurement fault.

The results of the research of the accuracy of determining the distance using the developed device and comparing the operation of the developed device with a laser line are shown in table 1.

TABLE I.

The real value, *mm*	200	500	1000	1500	2000	3000	4000	4500	5000	6000
Measured value, *mm*	199	499	998	1498	1998	2997	3997	4497	4997	5996
Absolute fault, *mm*	1	1	2	2	2	3	3	3	3	4
Relative fault,%	0,5	0,2	0,2	0,134	0,1	0,1	0,075	0,067	0,06	0,067
Laser ruler, *mm*	200	500	1000	1500	2000	3020	4020	4520	5020	6020

Analyzing the data of table 1, we can assume that the developed device gives a fairly accurate measured distance over the entire declared range of measurements, and therefore can be used to determine distances in the range from 200 to 6000 mm.

The next stage of the study of the developed device was to check the accuracy of the device when changing the angle of the module relative to the obstacle. Planning of the experiment: the module was installed at a distance of 1000 mm from the obstacle, then the variable was the angle of position of the developed device. The results of the experiment are shown in table 2

TABLE II.

The real value, *mm*	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Measured value, *mm*	1000	1000	1000	1000	1000	1000	1001	1003	1004	1005
Absolute fault, *mm*	0	0	0	0	0	0	1	3	4	5
Relative fault,%	0	0	0	0	0	0	0,099	0,299	0,398	0,498
Laser ruler, *mm*	1000	1150	1180	1340	4310	2300	2890	8150	6397	4239
Tilt angle, ˚	0	5	7	8	9	10	11	13	14	16

Analyzing the data in Table 2, we can assume that the module can be operated at an angle of inclination from 0˚ to 13˚. Further, the measurement error increases significantly and the accuracy of measurements is compromised.

Certain materials do not reflect the ultrasonic wave, so it is advisable to test the possibility of using the ultrasonic module as a means of measuring the level of various bulk materials, the ability to measure the distance to different materials.

Research conditions: During the experiment, the module was mounted horizontally with respect to the obstacle whose material was variable (paper, wood, glass, foam, cereals, cereals, foam rubber). According to the results of the experiments, materials that would absorb or break the ultrasound wave were not detected, so it is possible to recommend ultrasonic modules for measuring not only the distance to a certain object but also as sensors of the level of bulk materials in certain closed or open containers.

The designed sample of the portable measuring device is shown on Fig. 3.

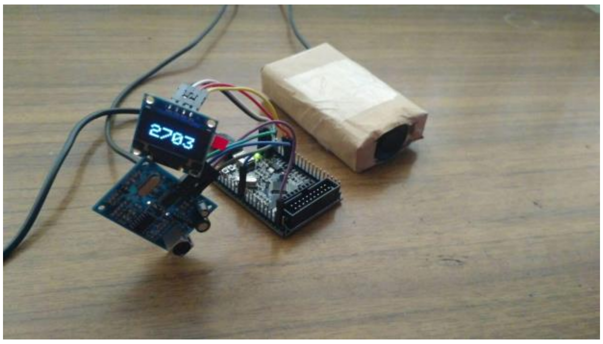

Figure 3. Appearance of the developed portable device

IV. Features of use of the measuring system

During the research it was observed that the accuracy of measuring the speed of propagation of ultrasonic waves in the measuring environment is influenced by external factors, so it is necessary to determine the influence of humidity and temperature on a given measuring system. It can be theoretically proved that the velocity of sound in gases is determined by the formula [3]:

$$c = \sqrt{\frac{jR(t-273.15)}{M}},$$

where $M = 28.95 - 10.934 RH \frac{P_n}{P}$, $j = 7/5$, R=8,

t – temperature;

P – pressure;

RH – relative humidity

P_n – saturated water vapor pressure (determined by temperature).

Based on this formula, where all components are constant, except thermodynamic temperature and humidity, we can conclude that the speed of ultrasound propagation in the medium (air) depends on these parameters. Because the environment in which the study is conducted is air, and the molar mass of air can only change from humidity due to the greater mass fraction of H_2O in its composition. The approximation of the air humidity change data over several days suggests that the effect of humidity on the speed of ultrasound propagation is rather small. The difference in the speed of sound between dry air (0%) and fog (100%) is 2 m/s at a temperature of 25 °C, and at 0 °C only 0.4 *m/s*. The speed of widening of sound waves depends on the nature and condition of the material environment in which they occur. In air at 3 °C, this speed is 331 *m/s*, and at 30 ° C -349 *m/s*. In technical calculations, the speed of sound is equal to 340 *m/s*. This is approximately its velocity at an air temperature of 15-16 °C. Therefore, we can conclude that the main effect is temperature. The program code includes a formula for determining the distance based on the known frequency and speed of sound propagation in the environment. The frequency of propagation of the ULTRASONIC wave in the medium is constant, and its propagation rate depends on the temperature and is variable [4].

The results of the experiments to check the effect of temperature on the readings of the ultrasonic device for measuring distance are shown in table 3.

TABLE III.

Distance, *mm*	at 19 °C, *mm*	at 25 °C, *mm*	at 15°C, *mm*
1000	1000	960	1030
2000	2000	1955	2044
3000	3000	2951	3048
4000	4000	3950	4052
5000	5000	4948	5056
6000	6000	5945	6060

Due to the single formula programmed in the memory of the microcontroller, as the temperature changes, a temperature error of measurement begins, which is directly proportional to the large deviation of temperature from the nominal value. To correct this temperature factor, a channel for measuring the temperature, which will consist of a temperature sensor, a measuring bridge and an amplifier, should be entered into the block diagram of the device.

V. Conclusions

Analyzing of existing methods and devices for distance measurement indicates the need to develop and research new inexpensive distance measuring devices. The materials describe the developed device and the results of its research, in particular the available angle of deviation of the measuring module from the horizontal during the measurements, the need to take into account the temperature to correctly determine the speed of propagation of the ultrasound in the measurement environment. Therefore, when using a developed measuring device, you can get accurate information about the distance to the object under correctly fulfilled operating conditions.

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