Development of Automatic Contactless Ultrasound Method of Soil Density Analysis

Andriy Moroz, Sergiy Filimonov

Abstract. Agriculture is one of the most important industries, providing the population with food and raw materials for a number of industries represented in almost all countries. The food security of the state and its citizens depends on the state of agriculture. The introduction of automated systems in agriculture will improve, facilitate and make this industry more productive. Determining the depth of plowing is one of the important parameters in tillage, on which the crop directly depends. Soil hardness monitoring is a real basis not only for ensuring energy savings in tillage, but also a basis for the rational use of resources to ensure a good harvest. The main tool for determining soil density is a penetrometer. The analysis of design features of modern models of penetrometers and the main results of researches of working processes in them is carried out. The disadvantages of electronic pin penetrometers are the need to accurately control the depth of immersion of the rod due to the smooth and perpendicular deepening into the ground, which increases the time of one measurement and the whole field, in addition, it is possible to separate the rod in stone and misinterpretation of the data, and some other technical nuances. In addition to technical shortcomings, in our opinion, the disadvantage of the modern penetrometer is its narrow, limited specialization, aimed only at measuring soil density. To study the propagation of ultrasonic vibrations in a medium with different hardness layers, a numerical simulation of the process was performed using the software package COMSOL Multiphysics 5.5. Which will give new foundations for the development of this area. The coordination of the ultrasonic signal emitter and the ground is considered separately. Experimental studies were also conducted to verify the proposed method for determining soil density.

Keywords: penetrometer, automation, soil density, piezoelectric transducer, modeling.

I. Introduction

Currently in Ukraine, and especially in our Cherkasy region, the agricultural sector is widely developed - huge areas are cultivated and sown with cultivated plants - wheat, corn, sunflower and so on. And thanks to this, the direction of growing crops is relevant. We end up getting food and many other foods from them. One of the most important areas for observation, study and improvement in agriculture is soil. The soil on which the crop is grown from year to year, which must be treated in different ways to achieve the best results. Today there are many ways of tillage: plowing, plowing, deep plowing (plowing the land at a certain depth), harrowing, peeling and others. It should be noted that each of these methods of tillage has different labor costs and material costs for cultivation.

Determining the depth of plowing is one of the important parameters in tillage, which directly affects the size of the crop. Soil hardness monitoring is a real basis not only for ensuring energy savings in tillage, but also a basis for the rational use of resources to ensure a good harvest. Excessive soil compaction limits the normal penetration of water, air and nutrients into the root system, which leads to a weakening of the growth processes of the whole plant and reduced yields. In such soils the rate of air exchange and nitrogen mineralization decreases.

The compacted action from wheels and caterpillars extends to 1 m in depth and to 0,8 m in the cross direction and can remain till the following vegetative period (Fig. 1). The quality of work when performing technological operations on compacted areas in the footsteps of agricultural machinery does not meet agronomic requirements. Traces up to 0.12 m deep remain on the surface of the field, according to which the soil density significantly exceeds the optimal values, the set depth of cultivation with cultivators is not maintained, up to 48% of grain seeds are not laid at the set depth, traction resistance of working bodies working on compacted areas increases. , the quality of harvesting works is deteriorating.

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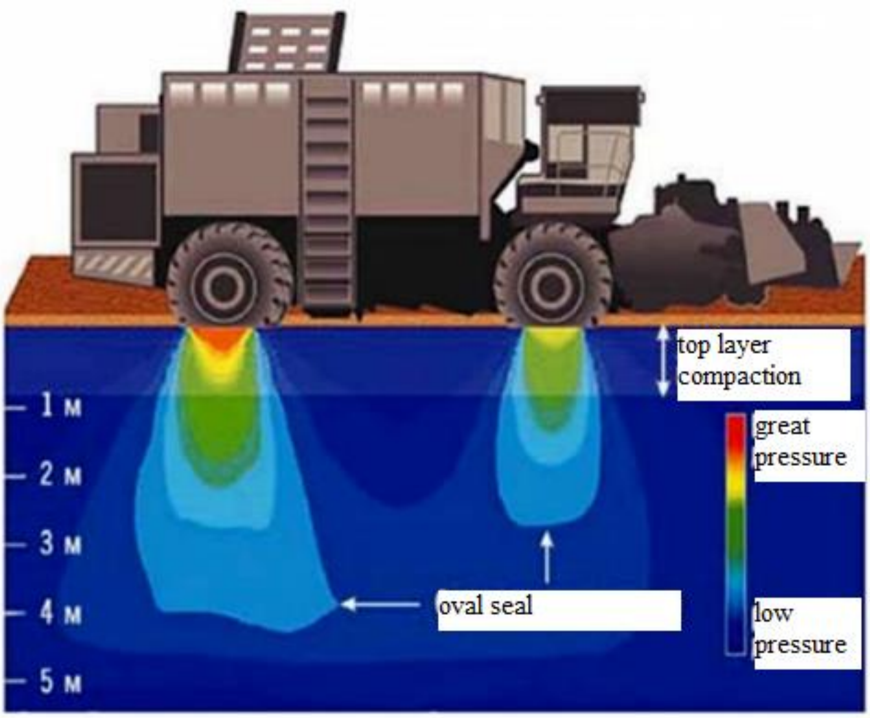

Fig. 1. Soil compaction from wheels

Graphically, the hardness is most convenient to show on the profile diagram. Naturally, the upper layers of plowing soils have the lowest hardness. The largest increase in hardness corresponds to the transition from arable to subsoil, where the plow sole is located. After passing the plow sole, the hardness decreases and remains constant (Fig. 2) [1].

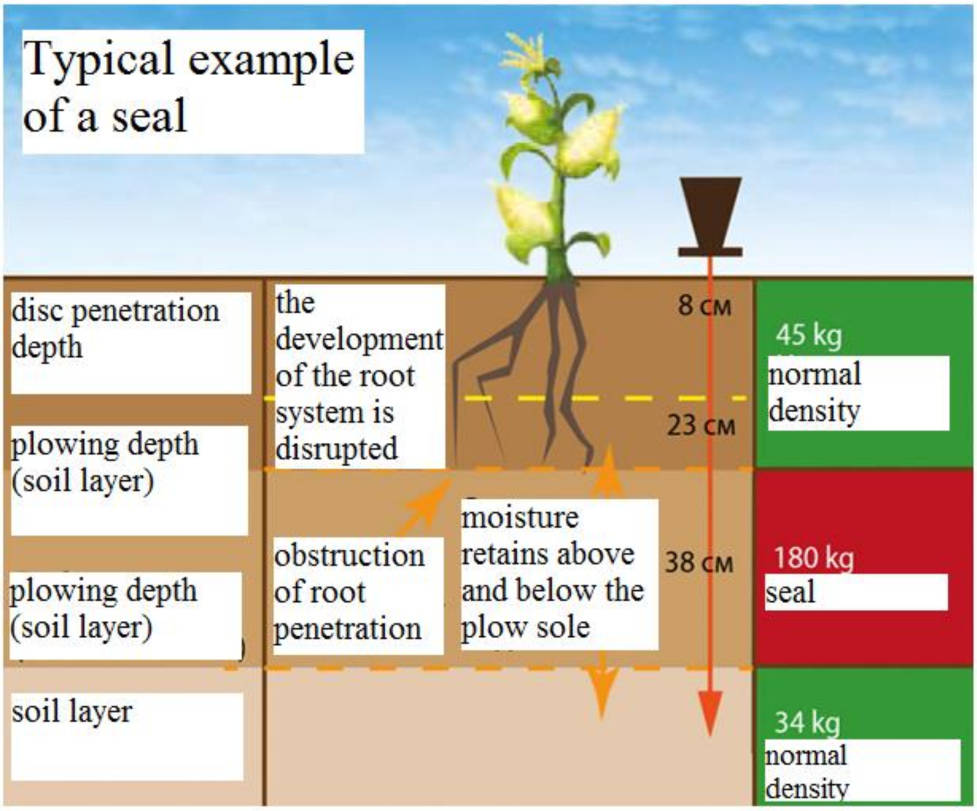

Fig. 2. An example of soil compaction at different depths

The main tool for determining soil density is a penetrometer. The penetrometer consists of a strain gauge and a electronic unit with a graphic display. Also included are extension rods and working tips. The principle of operation of the penetrometer is as follows. The metal rod with a tip is gradually sunk into the ground. The force with which the soil opposes it is registered by the force sensor.

The main disadvantages of electronic pin penetrometers are the need to accurately control the depth of immersion of the rod due to the smooth and perpendicular deepening into the ground, which increases the time of one measurement and the whole field, in addition, it is possible to separate the rod hitting a rock and misinterpreting the data, and some other technical nuances. In addition to technical shortcomings, in our opinion, the disadvantage of the modern penetrometer is its narrow, limited specialization, aimed only at measuring soil density [1].

Thus, the improvement and development of new methods for measuring soil density is one of the important tasks in the agrosphere.

This work is based on the concept of interaction of the ultrasonic emitter with the ground.

II. Literature Analysis

Thus, the previous section shows that any tillage system should be considered, first of all, in terms of regulating its density. The main device for measuring soil density is a penetrometer. Before you develop your own device for measuring soil density, you need to familiarize yourself with existing analogues. It is necessary to consider in detail and describe the characteristics of analogues, their advantages and disadvantages.

Prior to the invention of devices for measuring soil density, it was measured using the thumb, which is forcibly pressed into the soil. The rule of the "thumb" is as follows: a finger, which is completely immersed in the soil, gives a hardness of 1 MPa, to the first joint - 0.5 MPa, to the second - 0.25 MPa [1].

Today, there are fully automatic penetrometers that are placed on the body of the machine and in the process of scanning the soil density by emitting electromagnetic fields that measure the electrical conductivity of the soil (Fig. 3) [2].

The device works on the basis of electromagnetic induction, it contains five coils, four of which are tuned for transmission (radiation), and the fifth for reception. Each coil is responsible for a certain depth: the first - 0.5 m, the second - 0.7 m, the third - 0.9 m and the fourth 1 m.

Fig. 3. Topsoil Mapper soil density scanner

The disadvantages of this device are its high cost and mandatory mounting on the car. Use this device offline (manually, this is often necessary). Another significant disadvantage of this device is that the received data is downloaded and processed by paid servers. In addition, the result is very strongly influenced by soil moisture.

The automatic penetrometer from the DATAFIELD company is intended for automatic definition of consolidation of soil on various depths with binding of measurements to GPS coordinates. The system is an automated measuring rod that is installed on an SUV, ATV, truck or other equipment. The measurement process is controlled directly from the screen, which can be placed in the cab of the vehicle. Measurements are made at a depth of up to 60 cm. Data is stored with reference to GPS coordinates. Data transfer to the server is carried out through the GSM channel (Fig. 4).

The period of formation of the plow sole from 3 to 5 years depending on the type of soil. By making control measurements in the field, you may understand which fields or areas of the field require processing. This will save money on fuel and hours [3].

Fig. 4. Automatic penetrometer from the DATAFIELD company

One type of mobile penetrometer is a trailed automatic penetrometer (Fig. 5) [4].

Fig. 5. Trailed penetrometer GeoMil 200kN

The disadvantage of this device is also their high cost, significant dimensions and weight during operation. Other types of penetrometers include, if possible, the classic version, the basis of which is based on the deepening of the rod (metal pin) into the ground. These penetrometers can be divided into mechanical and electromechanical. In FIG. In Fig. 6 presents a mechanical pin penetrometer Datafield [5, 6].

Fig. 6. Mechanical pin penetration Datafield

The disadvantage of mechanical penetrometers is the need to record readings and build graphs manually, which greatly complicates the analysis of the soil, especially over large areas.

On Fig. 7 presents one of the designs of an automatic electronic-mechanical penetrometer with a rod (metal pin) [7, 8, 9].

Fig. 7. Automatic pin electromechanical Datafield penetrometer

The SC 900 Soil soil compaction meter (Fig. 8) is used to determine soil density. Among the characteristics of the penetrometer, an important component is the range of measurements equal to 0 - 7000 kPa [10].

Fig. 8. Soil hardness tester (penetrometer) SC900 Soil

In addition to industrial penetrometers, there are also homemade ones. Some design variants are shown in FIG. 9-10. In FIG. 9 presents a penetrometer developed on the basis of Arduino Nano by Altai University.

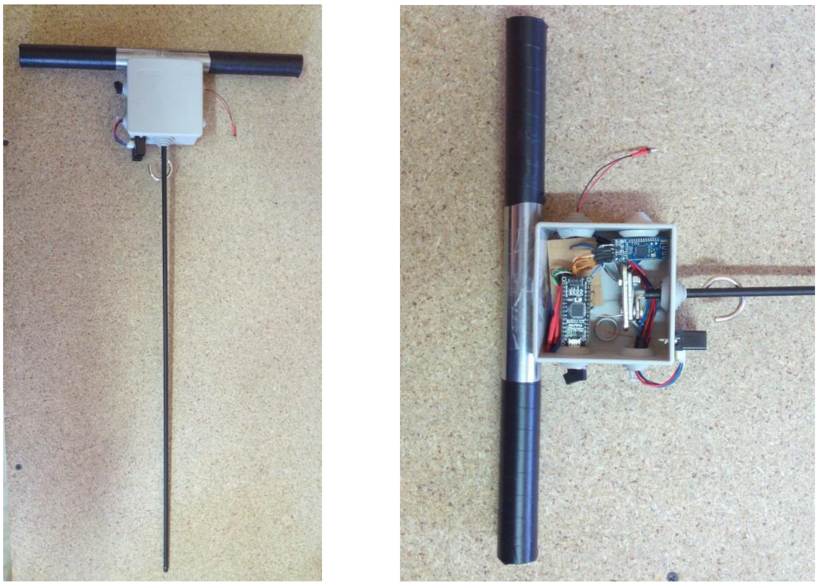

Fig. 9. Prototype of a device for monitoring the hardness of the soil depth at the base Arduino

The penetrometer, developed by the Department of Soil Science at Kasetsart University, Camphaengsaen Campus, Thailand, is shown on Fig. 10 [11].

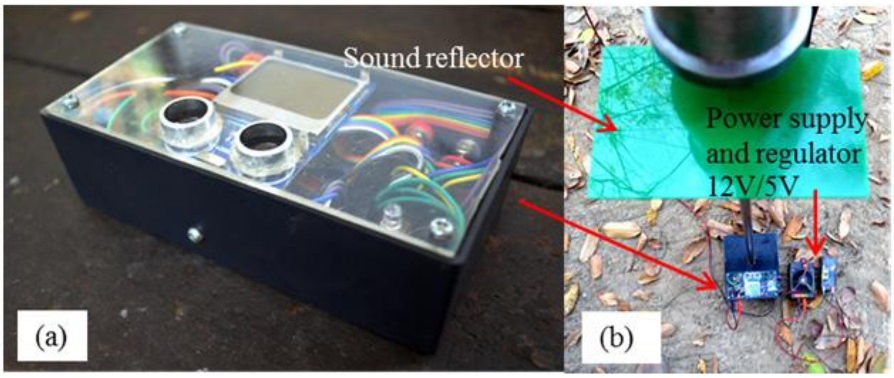

Fig. 10. Model of the finished system (a) and field node for measuring the penetration depth of the dynamic penetrometer (b)

The obvious disadvantage of most penetrometers is their price, penetrometers are a rather expensive measuring device, as well as overall dimensions. The main disadvantages of electronic pin penetrometers are the need to accurately control the depth of immersion of the rod due to the smooth and perpendicular deepening into the soil, which increases the time of one measurement and the whole field (therefore have to reduce the number of samples to 5-6 and calculate the average , which strongly averages the result), in addition, it is possible to separate the rod and clamp it in the ground, it is also possible to get into the stone, misinterpretation of the data, some other technical nuances. In addition to technical shortcomings, in our opinion, the disadvantage of the modern penetrometer is its narrow limited specialization, aimed only at measuring soil density.

From the above it is clear that it is necessary to radically reconsider the physical method of measuring soil density. Which will determine the size, weight, ease of use, speed of measurement of the device and cost.

III. Object, Subject, and Methods of Research

- **The purpose of scientific work**. Development of a new automatic non-contact method of soil density analysis.
- **The tasks of scientific work**:
- to analyze the design features of modern models of penetrometers and the main results of research of working processes in them;
- to model the propagation of ultrasound in a medium with different density layers;
- to propose a new method of non-contact measurement of soil density.
- **Objects of study**: processes of ultrasound propagation in the soil.
- **Subject of study**: ultrasonic vibrations in the soil.

Considering the existing structures of soil penetrometers and the physical principles on which they work, we can conclude that the following physical phenomena are used to determine the density: electromagnetic and mechanical, based on the force of elasticity. The main disadvantages of soil density meters that work on these physical phenomena are described in detail above.

Therefore, our work is aimed at finding a new method of measuring soil density. One of the non-contact methods is ultrasound. The advantage of this is high informativeness and simple technical implementation.

To study the propagation of ultrasonic vibrations in a medium with different density layers, a numerical simulation of the process was performed using the software package COMSOL Multiphysics 5.5. The obtained results will help to determine the feasibility of using the chosen method of studying soil density.

An important component of ultrasound is the coordination of the ultrasound emitter and the soil.

Experimental studies were also conducted to verify the proposed method for determining soil density.

IV. Results

Soil is an environment with different layers of density, especially in places where the plow sole is located.

An important issue is to determine how ultrasonic waves propagate in a medium with different density layers, ie how it is possible to record and interpret the results. To do this, computer simulations were performed using the software package COMSOL Multiphysics 5.5.

The study was based on the “immersion_ultrasonic_testing_setup model”. This model allows us to analyze the effect of mechanical oscillations in a medium with a variable density layer. Some results are presented at Fig. 11

In Fig. 11 shows the beginning of the mechanical impact and the first transition (signal reflection) of the mechanical impact between the layers of different densities, respectively. The figure shows how the second transition (signal reflection) between layers with different densities. Thus, the use of ultrasonic method of soil density study is appropriate. Slight fluctuations in the second transition indicate that the depth of the signal in a medium with different density layers depends on the power of the emitting signal.

An important issue in the use of the ultrasonic method as a density measurement is the coordination of the emitter with the ground.

When installing sensors in the soil from water-saturated to dry sand requires a matching link. In this case, the oscillations are transmitted from the medium to the matching link, and from the matching link to the sensor housing (Fig. 12). Without a matching link, the environment will fluctuate and the sensor will "stand still" [12].

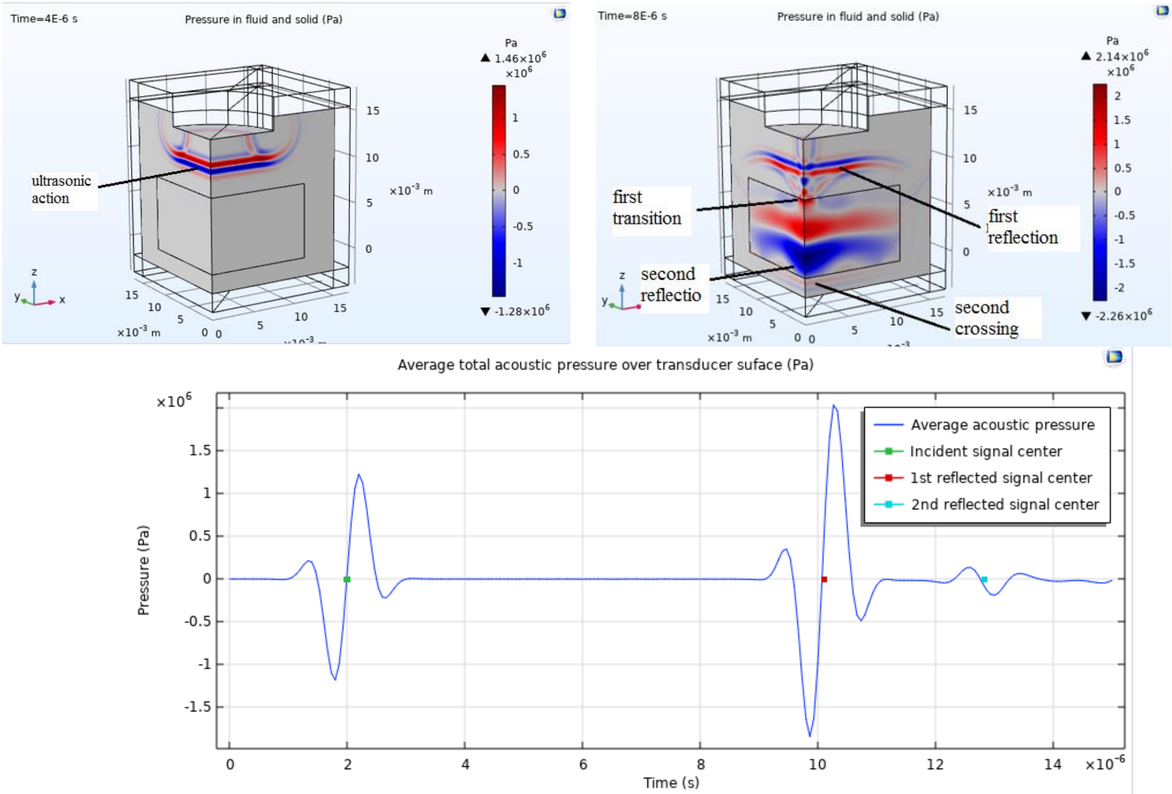

Fig. 11. Propagation of ultrasonic waves in a medium with different density layers - the beginning of the ultrasonic wave; the first transition between soil layers; the second transition between soil layers; signal graph emitting signal and reflected signal

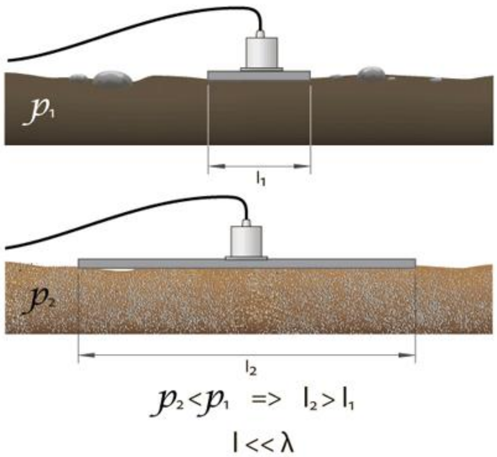

Fig. 12. Coordination of ultrasonic sensors on the ground

When installing ultrasonic sensors on the ground using an intermediate link - the connected mass, there are simple rules: the lower the soil density, the larger the area of the connected oscillating mass, and the overall dimensions of the intermediate link should be much less than the wavelength of the measured oscillations.

An NUR40A14T (steam) ultrasonic sensor with a radiation frequency of 40.0 ± 1.0 kHz and a directional angle of 80 ° ± 15 ° (-6dB) was used as an emitter and receiver of ultrasonic oscillations for conducting the experimental study [13]. The OWON smart DS7102 digital oscilloscope was used as the measuring equipment and the broadband high-voltage signal generator was developed on the basis of the IR2101 driver of the half-bridge circuit (Fig. 13).

Fig. 13. A high-voltage signal generator has been developed

The studies were performed as follows. From the generator the signal (40 kHz) was fed to the ultrasonic emitter, the ultrasonic signal was received by the receiver (sensor) and transmitted to the digital oscilloscope.

The experimental studies consisted of three stages. The first stage is to check the efficiency of ultrasonic sensors and obtain the original waveform in ideal conditions without interference in the air (Fig. 14). In the foreground is an ultrasonic transmitter and receiver (sensor), located opposite each other. The waveform on the receiver is shown in the background, the signal frequency is 40kHz and is a virtually pure sinusoidal shape.

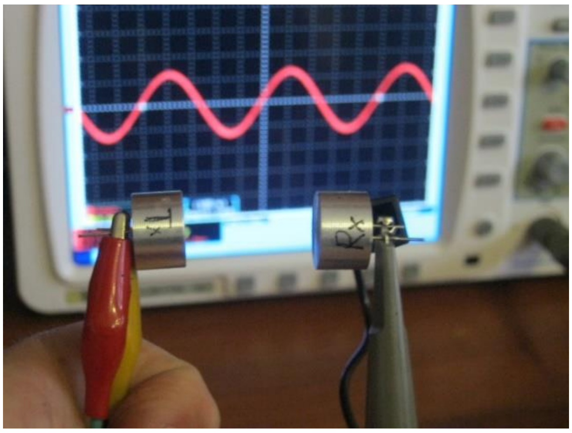

Fig. 14. Experimental study of the shape of the output signal from the sensor in the air

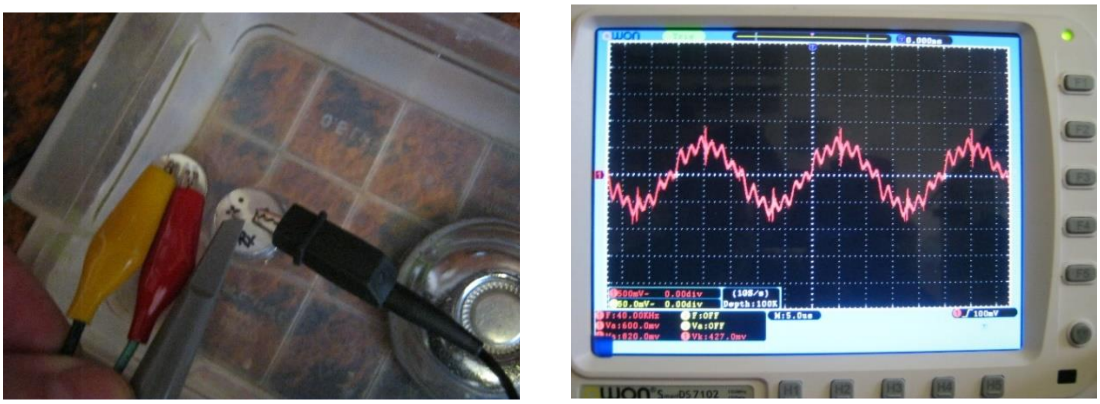

Fig. 15. Experimental study of the shape of the output signal from the sensor in water

The second step was to test the ultrasound in water, which is also like air medium with the same density. An important component of this study is to obtain the original waveform from the sensor. The studies were performed as follows. Water was poured into the tank and the operation of the ultrasonic sensor was checked (Fig. 15). Next, a stand was placed on the bottom of the tank, which performed the function of reducing the distance in the water to the obstacle (Fig. 16). The sensors were arranged in a planned manner, ie worked to reflect the signal.

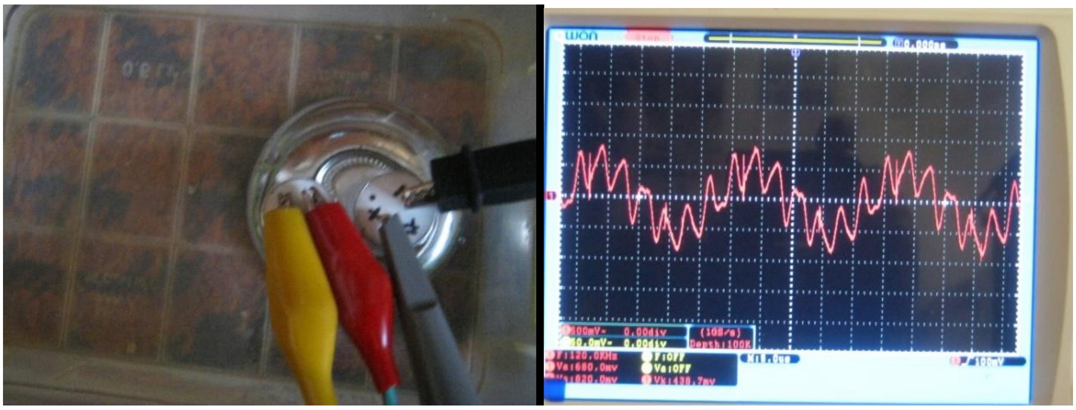

Fig. 16. Experimental study of the shape of the output signal from the sensor in water (reduced distance to the object of measurement)

From Fig. 15-16 shows how the shape of the output signal changes depending on the distance to the obstacle.

The last step of the study was to measure the ultrasound signal in the soil. The study was conducted as follows. The ultrasonic sensor and emitter were located systematically on the soil surface. The prototype is a flower pot in the middle of which was filled with soil with expanded clay and planted lemon, the shoots of which are already visible (Fig. 17).

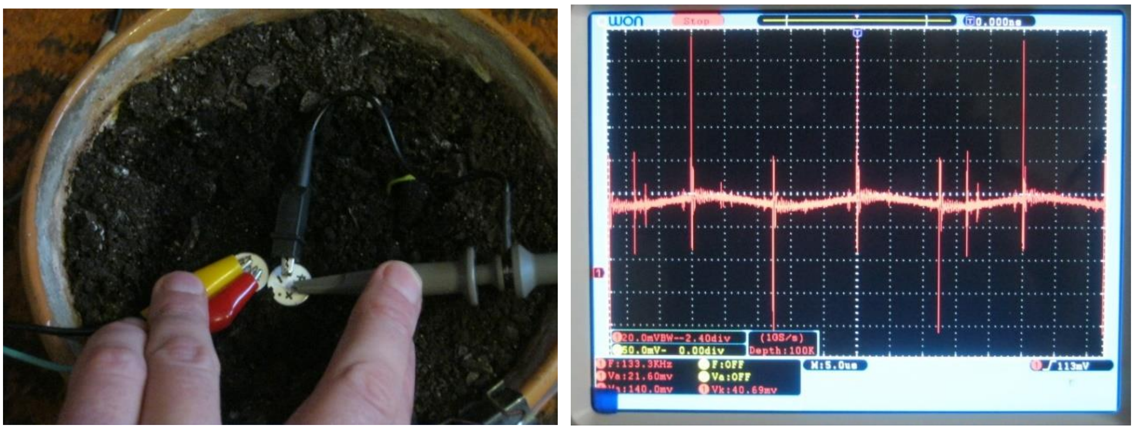

Fig. 17. Experimental study of soil density - a test specimen on the left and the oscillogram obtained from the sensor on the right

From the oscillogram of Fig. 17 it is seen that the ultrasonic signal reaching the limits of the transition of the density of soil components is registered in the form of bursts on the received signal.

The use of the NUR40A14T ultrasonic sensor will allow it to be used with the standard Arduino HC-SR04 ultrasonic module. For this purpose it is necessary to replace standard ultrasonic elements with the ones offered by us and to make minor changes in the electrical circuit (Fig. 18).

Fig. 18. Перероблений ультразвуковий датчик Arduino

The disadvantages of using a standard Arduino module are the inability to decode the received signal from the ground and a small measuring range.

Currently, experimental studies are underway within this project to improve this method.

V. Conclusions

1) The design features of modern models of soil density measurement are analyzed. Their main shortcomings have been identified.
2) Simulation of ultrasound propagation in a medium with different density layers is performed;
3) A new method of non-contact measurement of soil density based on ultrasound is proposed.
4) Experimental researches thanks to which expediency of use of the offered method is shown are carried out.
5) The results can be used in the design of ultrasonic systems.
6) The use of ultrasonic method of soil density may also allow to obtain several more soil parameters.

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