Systems for remote monitoring of earth pre-destruction

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Abstract. Continuous monitoring of earth's soil displacement is important for understanding the dynamics of the landslide process and its continuous evolution, and for developing mitigation measures as well. Despite its importance, it is not always used due to its high cost and the need to integrate with additional sensors to track factors that control movement. To prevent these problems, we developed systems for remote monitoring of the pre-destruction of the earth's soil based on a fiber-optic sensor and a humidity sensor. The system registers certain parameters, functions as a soil displacement detector, and also sends data to the server. Soil movement and humidity are displayed graphically through the website interface. The system can also recognize sudden ground movements as a sign of landslides.

1. Introduction
In recent years, fiber-optic sensors (FOS) have been rapidly developing, and optoelectronic systems are being developed on their basis. Thanks to the technologies mainly using fiber-optic for transmitting analog, digital and other signals, other distinctive features have appeared and, as a result, they can be used for other purposes, in particular, for detecting mechanical damage, violations and defects in structures, bridges, overpasses, retaining walls, reinforced earth embankments, buildings, etc. by measuring the characteristics of optical signals.

Currently, we are developing a system for optoelectronic monitoring of the earth's soil displacement based on two types of sensors (displacement and humidity sensor). In previous publications, the concept or idea of the implementation of this method, as well as the principle of the system functioning were substantiated [1-2].

Landslides or land displacements in some cases do not occur spontaneously, but there are signs of ground movement. The above signs can actually be converted into an early warning system that will aid in tracking down signs of landslides. In most cases, the occurrence of a landslide occurs due to the loss of equilibrium of the soil mass or due to changes in one or several parameters that contribute to the preservation of the stability of the mass itself. In addition, studies show that exceeding the norm of soil humidity in excess of 40-45% also increases the likelihood of a landslide. This process is due to the connection with a water-saturated landslide body (atmospheric precipitation, the rise of the groundwater level, artificial waterlogging of soils) [3], as well as the development of mineral deposits, for example, oil and gas deposits in natural regimes without water injection into the reservoir due to a decrease in efficiency exploitation of deposits due to the breakthrough of injected water into producing wells or the absence of hydrodynamic interaction between the wells [4–10].
2. Materials and methods
Taking into account these features and conditions of the probability of rock displacement, the developed system controls the following types of basic parameters: mechanical movements and relative humidity of the soil.

In addition to these parameters, the system sends the following additional parameters to the server via the GSM communication channel: laser power level Tx; received signal level Rx; working temperature of the developed device; battery charge level.

Based on all the above factors, requirements and various features, we have developed a special device for monitoring and early warning of landslide processes. The connection diagram of this device is shown in Figure 1.

![Figure 1. Wiring diagram for modules and sensors](image)

The device consists of the following blocks: SFP-module; Arduino Uno board; SIM 800L GSM module; power supply.

Besides these main units, the device is also equipped with other auxiliary parts, such as soil humidity sensor; optoelectronic sensor; LED indicator; piezoelectric element; battery (3.7 V, 1100 mAh).

Below is the description of each module and sensor used in the development of the device.

**SFP module.** We selected a FTLF8519P3BTL-HW sample from Finisar (Malaysia). SFP (Small Form-factor Pluggable) is a standard for compact optical transceivers, used as a laser and an optical beam receiver (Figure 2.). This module is equipped with a built-in DDM (Digital Diagnostic Monitoring) protocol operating on a two-wire interface, which in turn is responsible for digital monitoring of the manufacturer's parameters (voltage, temperature, Tx laser power, Rx received signal level) in real time. DDM generates 8-bit addressable reporting information (1010000X (A0h) or 1010001X (A2h)), which contains instant reports on diagnosed system parameters [11].

Operational and diagnostic information is monitored and transmitted to the microcontroller in the SFP, which is accessed via a 2-wire serial bus (also known as the "I2C" or "I2C" protocol). The transceiver generates this diagnostic data by digitizing the internal analog signals. In addition to
generating digital readings of the internal analog value, the device generates various status bits based on comparisons between the current value and the factory preset [12].

Features and technical parameters of the product: duplex data transmission channels with a speed of 1.25–2.125 Gbps; built-in functions of digital diagnostics DDM; VCSEL oxide laser transmitter; wavelength 850 nm; duplex LC connector; RoHS compliant; signal propagation range up to 550 m on MMR 50/125 microns and 300 m on MMR 62.5/125 microns; metal housing to reduce electromagnetic interference; power supply: 3.3–5V; power dissipation <500 mW; operating temperature range: -40 °C to 85 °C; hot-pluggable;

Applications: 1.25 Gbps 1000Base-SX Ethernet; dual-band optical channel: 1.063/2.125 Gbps; wireless communication CPRI, OBSAI, LTE [5].

Figure 2. SFP module FTLF8519P3BTL-HW, 850 nm

The Arduino Uno controller is built on ATmega328 chip (Figure 3). The Atmel® ATmega328P is a low-power 8-bit CMOS microcontroller based on the RISC architecture enhanced by AVR®. The platform has 14 digital I/Os (6 of which can be used as PWM outputs), 6 analog inputs, 16-MHz crystal oscillator, USB connector, power connector, ICSP connector, and reset button. The AVR® core combines a rich instruction set with 32 general purpose working registers. All 32 registers are directly connected to an arithmetic logic unit (ALU), allowing access to two independent registers in one instruction executed in one clock cycle. In standby mode, the processor stops, allowing the SRAM, timer, counters, USART, 2-wire serial interface, SPI port, and interrupt system to continue running [13].

To work, one needs to connect the platform to the computer using a USB cable or to a supply power using an AC/DC adapter or battery. The Arduino Uno provides a number of options for communicating with computer, another Arduino or other microcontrollers. The ATmega328 chip has a UART transceiver that allows for serial communication via digital pins 0 (RX) and 1 (TX). The ATmega16U2 chip built into the board provides serial communication capability using USB drivers. The IDE software provides a serial monitor that is used to send or receive text data from the board. The device is manufactured using Atmel's high-density non-volatile memory technology. The built-in ISP flash memory allows program memory that can be reprogrammed in the system via the SPI serial interface, using a conventional non-volatile memory programmer, or an on-chip boot program running on the AVR core. The loader program can use any interface to load the application program into the flash memory of an application. The Arduino Uno is programmed using the Arduino software, which is a cross-platform application referred to as IDE and written in Java.

Specifications: Microcontroller type: ATmega328P; microcontroller supply voltage: 5 V; recommended board supply voltage: 7–12 V; maximum allowed board supply voltage: 6–20 V; digital inputs-outputs: 14 (of which 6 support PWM); PWM modulation outputs: 6; analog inputs: 6; permissible current of digital outputs: 20 mA; allowable current of 3.3 V output: 50 mA; Flash memory size (FLASH): 32 kB (of which 0.5 kB is used by the bootloader); random access memory (SRAM): 2 kB; the amount of non-volatile memory (EEPROM): 1 kB; clock frequency: 16 MHz [13].
Figure 3. Arduino Uno board

**GSM module SIM 800L.** The GSM/GPRS module on the SIM800L chip is a small GSM modem that can be used in various projects and purposes. In our case, it serves as a transmitter of diagnosed parameters, a receiver of code (control) SMS commands, and it also sends SMS notifications if the parameters go beyond the established safe operational limits. In addition to these features, this module provides data exchange via GSM and GPRS channels using full duplex mode, i.e. the state of the investigated object can be monitored wherever there is Internet coverage.

A SIM card is installed in the module; there is a built-in antenna and an output for one more antenna. Power is supplied to the board through a DC-DC voltage converter. It is also possible to connect to a different power source. Connection interface is UART. The central microcontroller of the SIM800L module is the Mediatek ARM MT6261 chip. A 4-band (GSM850/GSM900/DCS1800/PCS1900) RF7198 transceiver is responsible for GSM/GPRS communication [14].

*Technical parameters:* supply voltage: 3.7V–4.4V; standby current consumption: 0.7 mA; peak current: 2 A; UART speed: 1200–115200 baud; SIM card format: microSIM; working range: EGSM900, DCS1800, GSM850, PCS1900; transmission power DCS1800, PCS1900: 1W; transmission power GSM850, EGSM900: 2 W; network mode: 2G; dimensions: 25 × 24 × 4 mm [15].

Figure 4. SIM800L module

**Humidity sensor.** The Arduino soil humidity sensor is designed to detect the humidity level of the earth's soil in which it is immersed. An analog value is supplied to the S pin, which can be transmitted to the controller for further processing, analysis and decision making. The sensor has a red LED that signals the presence of power supply to the sensor.

Module specifications: supply voltage: 3.3-5 V; consumption current 20 mA; output: analog; detection area: 16×30 mm; dimensions: 62 × 20 × 8 mm; working temperature: 10–30 °C [16].

Figure 5. Humidity sensor
**Fiber optic cable (sensor).** Optical fiber can be used as a sensor to measure voltage, temperature, pressure and other parameters. Small size and virtually no need for electrical power give fiber optic sensors an advantage over traditional electrical sensors in certain areas. A G.652 cable (single-mode) with an LC-SC patch connector for connecting to an SFP module was selected as a fiber-optic sensor. G.652 is an international standard describing the geometric, mechanical and transmission attributes of single-mode optical fiber and cable, developed by the International Telecommunication Union (ITU-T) Standardization Sector, which defines the most popular type of single-mode optical fiber (SMF) cable. Single mode fiber is designed to carry one mode of light for simultaneous propagation. Among all types of single-mode fiber, G.652 is by far the most widely used single-mode fiber optic cable worldwide. This fiber category is also known as standard SMF. G.652 fiber is rated for a zero-dispersion wavelength of about 1310 nm, so it is optimized for operation in the 1310 nm range and can also operate at 1550 nm.

**Cable Specifications:** Alternative Name: Standard SMF/Zero Dispersion Shifted Fiber; working wavelength: 1310, 1550, 1625 nm; dispersion temperature: 1310 nm; subclasses: A-B-C-D; attenuation parameter: less than 0.5/0.4 dB/km at 1310/1550 nm; macrobending loss: less than 0.5 dB at 1550 nm; PMD parameter: less than 0.5 ps/√km for G.652C and 0.2 ps/√km for G.652D; applications: LAN, MAN, access networks and CWDM transmission; features: waterproof coating [17].

![Figure 6. G 652 Single-mode optical cable with LC-SC connector](image)

**Charging and power supply module.** The board includes a charging circuit, a status LED, a battery connector (JST) and a micro-USB connector. A small mounting hole makes it easy to integrate this charger into a project. The LiPo Charger Basic is set to 500mA by default. The default output of the standard USB port is 500mA. This module has a DC voltage converter from 3.7 V to 5 V [18]. In our system, some modules are powered from a voltage of 5 V, and a constant energy battery with a nominal value of 3.7 V, that is, we have a need for 5 V, which is why this module was selected.

![Figure 7. LiPo Battery charging module](image)

**Lithium ion polymer battery.** A battery with a nominal value of 3.7 V, 4000 mAh was selected as a constant power source.
Figure 8. Li-ion battery

**Connection diagram and block diagram of the device**

The device connection diagram is shown in Fig. 9.

![Connection diagram](image1)

**Figure 9. Functional block diagram of the device**

The system operates as follows. After the system is started by pressing the power button, all modules and blocks go to the active mode of operation. First of all, the Arduino Uno central board reads the primary data memory from the EEPROM memory, that is, it familiarizes itself with the preset settings. At this stage, the Arduino Uno reads the preset values of the parameters, such as: the average power level $R_x$, the permissible deviation of the minimum and maximum power levels ($R_{x_{\text{min}}}$ and $R_{x_{\text{max}}}$), the maximum permissible humidity value ($\text{Hum}_{\text{max}}$). In addition, the module initializes the subscriber number from the EEPROM memory, which will subsequently send an SMS-notification.

The second step is to establish communication between the SFP-module and the Arduino Uno board. As stated above, this type of communication is carried out through a two-wire interface. The Arduino Uno board communicates with the SFP module via a two-wire interface, and this data is generated using the DDM protocol built into the SFP. This protocol has information about the digital control of SFP-parameters, such as: the level of the received signal $R_x$, the power of the transmitter (laser) $T_x$, and the supply voltage. DDM generates various types of data in the form of code sequences under the corresponding element. The number of such elements is 256, each element has 1-byte information capacity. For example, the 104th and 105th elements are responsible for the $R_x$ level, the 102nd and 103rd elements contain the $T_x$ data, while the 96th and 97th elements include information about the SFP temperature level [11]. Using the values of these parameters, you can carry out diagnostics and make appropriate decisions in the future, that is, notify, trigger alarms, etc.
The next step is to start the process of measuring parameters. The measurement is carried out directly through two sensors. The first sensor is a fiber optic sensor. As it was mentioned above, a single-mode G.652 FOC with an LC-SC connector is used as this type of sensor. The second sensor is a soil humidity sensor. This sensor has 2 power inputs and 1 analog output for data transmission. It connects to the corresponding analog input of the Arduino.

Next, the Arduino board establishes communication with the GSM module SIM 800L. This type of communication is based on a serial TTL interface. A special LED indicator is provided on the developed device, the blinking of this LED means that communication has been established between the Arduino board and the GSM module. Before sending data to the server, the Arduino generates a request to the GSM module with the “APN Configurations” command, that is, it configures the module for Internet configurations so that the module connects to the Internet via the GSM communication channel. Accordingly, the GSM module SIM 800L performs the function of a transmitter of information to the Web Server in the form of an HTTP protocol. Information between the server and the GSM module is exchanged based on the Client-Server scheme.

The information received by the server is subsequently stored and converted in the form of a special graph that shows various parameters (device temperature, Rx level, Tx level, humidity level, built-in battery charge level, as well as levels of the last critical values of these parameters) in real time (Figure 10). The data in the server is refreshed every 5 seconds. In addition to the main parameters, the "charge level of the built-in battery" is included in the list of sent data in order to inform the operator in the Monitoring Center about the state of the energy source, since this device is supposed to be used in portable applications, it is recommended to periodically change the battery.

A sequential stage in the functioning of the system is the process of generating notification and notification signals. The ATMEGA microcontroller is reprogrammed so that, under its order, the GSM module continuously sends information to the server about the parameter levels, and it also sends an SMS notification if the parameter values exceed the threshold of the set limits. Simultaneously with sending SMS, the system issues an alarm sound by means of a piezoelectric element connected to the central board.

Taking into account the dynamic variability of the Rx calibration level, this parameter must be reconfigured every time, that is, if you install the device on a different object, then the preset values cannot coincide with the current situation. This problem was solved with the help of special code-containing SMS commands. You can increase the sensitivity of the system by bringing the Rx threshold values closer to the Rx calibration level, and you can also change the humidity threshold level directly, just by sending SMS commands. Moreover, almost any subscriber can send and change the calibration levels of the measured parameters in order to increase the consumer level.

Figure 10. User web-interface of the system
3. Results and discussion

The algorithm of developed device operation is shown in Figure 11. Below is a description of the sequential step-by-step actions of this algorithm. The tasks performed by the algorithm are as follows: continuous monitoring of the state of the earth's soil and early warning of the occurrence of landslide processes.

The process begins by running a preview of the saved configurations. At this stage, the algorithm will read the preset parameters (threshold Rx values, permissible humidity level, linked subscriber number, which will subsequently send an SMS notification). The listed data is stored in the EEPROM of the system memory.

Next comes the initialization of the connection, i.e. inter-unit and inter-module connections in the system are established: between the SFP module and Arduino Uno, between SIM 800L and Arduino Uno, sensors are initialized, etc.

The next step in the algorithm is to open a loop of repetitive actions. This cycle is performed as long as the device is powered continuously, that is, until the measurement or monitoring ends.

Under the main cycle there is a sub-cycle for measuring the optical parameter Rx and the humidity parameter $Hum$. It is known that in the operation of various monitoring systems, false alarms are detected, false alarms are turned on, as well as inadequate processing of information received from special sensors.

The appearance of such problems is caused either by incompleteness or unpredictability of various situations in the development of this algorithm. Since our algorithm monitors the state of the earth's soil, and our sensors will be directly buried under the soil layer, in our case there is also a possibility of false alarms. Due to the existence of analog connections between the modules, internal noise occurs in the system, which leads to the appearance of false impulses. Subsequently, these pulses also lead to a false alarm. In addition to these problems, there is an error threshold for each sensor and requires a special procedure to compensate for this threshold. To avoid the above problems, the system measures each parameter $n$ times ($i = 0; i < 50; i ++$, in our case 50 times) and calculates the average value of these parameters.

After measuring and determining the average values, the algorithm proceeds to the stage of sending the average values to the server via the HTTP protocol. At this stage, the Arduino Uno central board collects data from the sensors and transmits it to the GSM module. This type of information exchange is carried out on the basis of a TTL serial interface. In turn, the GSM module sends data to a remote server via Internet channels. The GSM module and the server work according to the Client-Server scheme.

Then the algorithm goes to the decision-making stage, i.e. the instantaneous and threshold values of the parameters are compared. If the system, when comparing the values, determines the slightest deviation of the values from the threshold, then it goes into the alarm mode, if not, then it remains in the standby mode (Figure 12). The system automatically sends an SMS notification with text containing information about the corresponding deviation of values in case the parameter values exceed the established safe operational limits, and it also simultaneously updates the data in the server.
Figure 11. Algorithm of the landslide monitoring device operation
The last step in the algorithm is calibration. This stage is performed when the system needs to be reinstalled on a new object/site. The calibration process is performed by sending special code containing SMS commands. The system recognizes the text in the SMS message as entering new parameters or configurations. After reinstalling the system to a new object, it is necessary to enter the current level of the Rx signal as Rx\text{norm} (average level of the rest mode) into the memory. Rx_{\text{min}} and Rx_{\text{max}} must be set sequentially reducing the values between these parameters, an increase in the sensitivity of the optical sensor is achieved. In addition, you can readjust the permissible humidity level to a certain value (from 0 to 100). After installing new configurations, the system sends a change report in the form of an SMS message.

All these above stages, performed by the developed algorithm, constitute a full cycle of work. In fact, the algorithm functions in a more complex way; several parallel processes occur at the stage of tasks execution. This algorithm is simplified and more refined.

4. Conclusion
In the field of geophysical research, the landslide early warning system is one of the most difficult studies. This article presents a landslide early warning system based on a fiber-optic sensor and a soil moisture sensor using an ATMEGA 328 microcontroller and subsequent data transmission via a GSM module. The prototype was developed based on the Arduino Uno board to provide a low-cost, improved platform for continuous monitoring of earth soils and landslides. The developed monitoring system takes into account the time of spontaneous soil displacement as an indicator of the degree of danger of sudden landslides. The results of monitoring soil shear values and soil moisture values can be used to indicate the occurrence of landslides. A warning about the danger of landslides for the surrounding population can be given by means of a siren, which can sound at any time when a level of danger arises.

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