The System of Temperature and Conditioning Control in Industrial Grain Storages

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Abstract

The article describes the approach to temperature and humidity control in industrial grain storages. The system involves the use of smart sensors, means of measurement data collecting and its transfer to the server. Through the use of the cloud environment, the system allows synchronizing measurement data received from anywhere in the world, which will be of benefit to large Agro holdings.

Keywords [1]

smart grain storage, elements of industry 4.0, temperature control, humidity control

1. Introduction

Grain mass (grain or seeds) storage method depends mainly on its physical and physiological properties and is also determined by the type of active aerator (ducted, floor-standing, portable, etc.). But it can be clearly stated that both temporary and long-term storage of grain masses should be technically provided so as to prevent losses and deterioration of the product.

- In recent years, silos have become widely used for grain storage. They can be of different capacities (up to 10 thousand tons and more), made of steel, aluminum and various alloys. The most common version is a cylindrical structure made of sheet steel. The advantages of metal silos include convenience of their loading and unloading. They are easier and faster to construct (assemble), and the cost of one ton of such capacity is 1.5-2 times less than an elevator made of reinforced concrete. The advantages of such storages also include their low space requirements. Thus, it is possible to place three metal storages with a total capacity of 15 thousand tons on the territory, which is necessary for the construction of the warehouse to store 5.5 thousand tons. Metal storages reliably protect grain masses from damage by rodents. They are also fireproof and convenient to gas disinfection, forced ventilation, etc. Silos must meet a number of requirements. Thus, along with the resistance to pressure of the loaded grain mass, wind and unfavourable effects of atmospheric factors, they should contribute to the preservation of the initial quality of the grain mass. The main disadvantage of such grain silos is that only dry and average humidity grain can be safely stored there. However, practice shows that sudden temperature change leads to the creation of significant temperature gradients, resulting in the phenomenon of thermal conductivity of the grain mass and formation of condensed moisture in it. The latter factor stimulates the activation of the bacterial flora and a number of other negative developments. Forced ventilation or aeration is an effective tool in fighting them, and its main functions include: facilitation of significant improvement in the quality of grain, as the required humidity and temperature are being maintained throughout the period of its storage; rapid cooling of warm (hot) grain to the desired temperature, which reduces the likelihood of spoilage and pest infestation. Such optimal humidity and thermal conditions ensure the prevention of decay processes and mold attacks on the grain surface, as well as damage by destructive pests.

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2. State of arts

According to the storage technique of grain products, it is necessary to control the temperature of bulk grain to prevent deterioration of quality and loss of grain as a result of self-warming. The technologist, who knows the initial values of temperature in different bulk grain layers, analyzes its changes over time and, in case of exceeding the allowable value, performs technological operations for artificial cooling by forced ventilation or moving grain from one silo to another. Given the fact that these operations have a negative impact on product quality, they should be carried out on the basis of reliable information about the bulk grain temperature. To detect the bulk grain areas with higher temperature in a timely manner, the tools for temperature control must ensure high sensitivity and allow for minor instrumental and methodological contributing errors in measuring the grain temperature and humidity.

3. Synthesis of local temperature and humidity control system

To achieve the goal of monitoring the quality of grain storage, it is necessary to synthesize a temperature and humidity control system for storage silos, which will allow monitoring the quality of grain during storage. Due to the large volume of grain, which should be stored, it is advisable to lay vertical measuring pipes inside the silo, the body of which consists of durable reinforced plastic where the sensors are to be placed (Fig. 1). This approach will provide the most informative parameters and give the most accurate measurement information from a larger volume inside the silo, and as a result, it will be possible to react swiftly to grain overheating or change of its humidity based on the change of hydrocarbon dew point. This is critically important, because grain heating process in such large volumes can develop locally, in small volumes and spread quickly. The transmission of measurement information between the sensors and the storage medium will be carried out by the contact method, as this method is the most reliable, and the second factor underlying this choice is the need to power the sensors. The contact network is laid with the above-described reinforced plastic tubes.

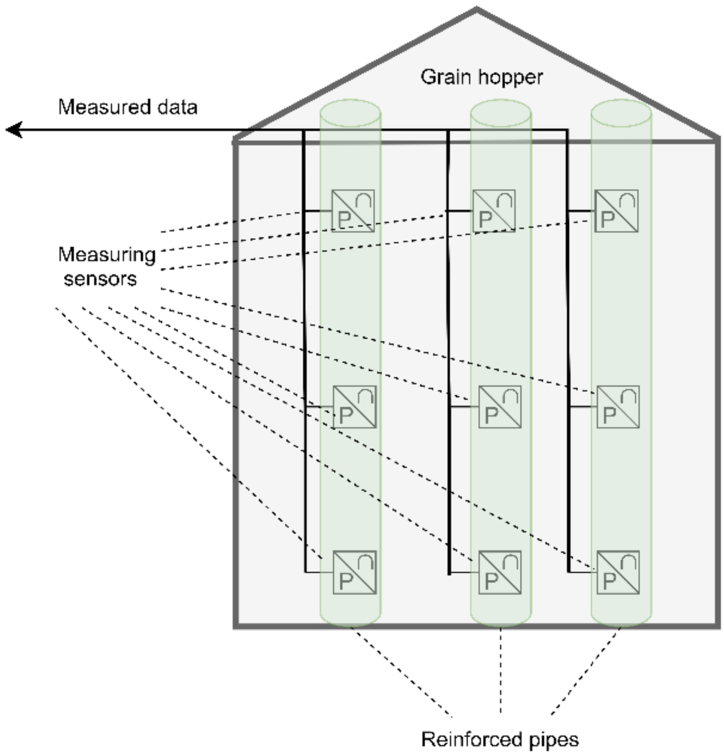

Fig. 1. The principle of placing sensors inside the silo

If the internal parts of the silo require the installation of reinforced pipes to control the temperature and humidity of the grain effectively, the near-wall areas can be equipped with measuring sensors that will cut into the technical holes of the silo. Since the measuring system uses an MTR series sensor with IP65 moisture resistance class (table 1), it is safe to say that the measuring instrument is protected from moisture and dust, so it can be installed on the street and can withstand weather changes. Since the dew point occurs primarily on the wall areas, it is advisable to use more sensors on the wall area itself.

Table 1.
Technical specifications of MTR series sensors

Version	MTR-731	MTR-732
Measurement range	0,0 ~ 100 % scale Absolute humidity 6,0 ~ 56,0 % WME*	Temperature: -40 ~ 60°C, 20 ~ 80°C, 0 ~ 100°C Humidity: 0,0 ~ 100 % scale Absolute humidity 6,0~56,0% WME
Accuracy (at 25°C)	Humidity ±2%	Temperature ±0,4 °C Humidity ±2%
Stability	Better than 1% per hour	
Temperature compensation	±0,02% / °C	
Response time	Not more than 3 seconds	
Output Humidity: 0,0 ~100 % Temperature: -40 ~ 60 °C	Output 4 ~ 20 мА, double-phase	Temperature: output 4 ~ 20 mA, double-phase; voltage 0 ~ 2В DC for a phase
		Humidity: output 4 ~ 20 mA, double-phase
Power supply unit	12 ~ 40В DC, > 120 mA	
Operating temperature	-40 ~ 60 °C	
Weight	190 g	

The local system of temperature and conditioning control in “Silo” grain storages consists of MTR-731 and MTR-732 sensors, which are located inside the hopper and along its perimeter (Fig. 2).

Power supply and measurement information is obtained by the contact method. The fire-resistant Profibus-DP cable is used to ensure contact, and it has been optimized by increasing the transmission speed and low installation costs. The cable has been designed for communication between automation systems and decentralized peripherals in the field environment. Profibus-DP replaces the usual parallel data transmission with a voltage of 24 V or 0 - 120 mA.

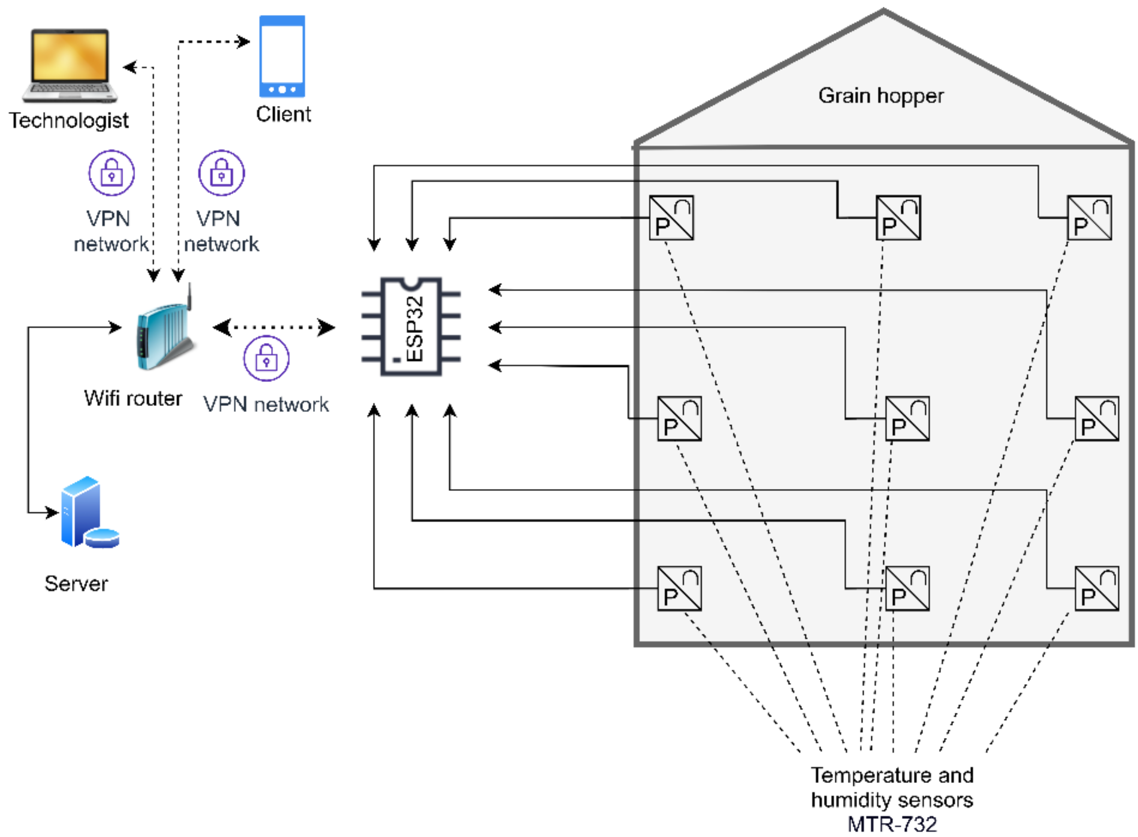

Fig. 2. Graphic representation of the local part of the grain storage temperature and humidity control system.

ESP-32 (Table 2) is responsible for collecting and short-term accumulation of measuring information. It is powered by a common power supply of 24V sensors, using a DC-DC converter based on the FP5139 chip with a voltage drop to 3.3 V.

Table 2.
Basic technical specifications of ESP- 32

USB-UART converter	CP2102
Supply voltage	5V
Maximum current of constant-voltage regulator	800mA
Wi-Fi Standards	FCC / CE / IC / TELEC / KCC / SRRC / NCC
Protocols	802.11 b / g / n / d / e / i / k / r (802.11n up to 150 Mbit/s)
A-MPDU and A-MSDU	Keeping guard interval at 0.4 s
Frequency range	GHz 2.4 ~ 2.5
Bluetooth protocols	Bluetooth v4.2 BR / EDR and BLE specification
NZIF radio receiving set with a sensitivity of	-98 dBm
Transmitter	Class-1, class-2 and class-3 AFH
Hardware and interfaces	SD, UART, SPI, SDIO, I^2C, LED PWM, Motor PWM, I^2S, I^2C, IR GPIO, ADC, DAC, LNA preamplifier
"On-board" sensors	Hall sensor, temperature sensor
Oscillators	crystal 26 MHz and 32 kHz

Micromodule power supply	2.2 ~ 3.6 V
Operating current, average	80 mA
Operating temperature range	-40 °C ~ + 85 °C
Distance between contact foams	25.5 mm
Software support	Modes of Wi-Fi Station / softAP / SoftAP + station / P2P
Protection	WPA / WPA2 / WPA2-Enterprise / WPS
Encryption	AES / RSA / ECC / SHA
Network protocols	IPv4, IPv6, SSL, TCP / UDP / HTTP / FTP / MQTT

Since the ESP-32 has 18 channels (ADC) "on board", it is possible to connect 18 sensors, but it should be noted that if there is a need to increase the number of ports, there is a possibility to use up to four external ADS, for instance 8-channel ADS1234. That is, it is possible to get a total of 50 channels, which is enough to perform the task. Given the fact that, technologically, the grain bulk cannot change its humidity and temperature in a matter of minutes, there is no need to obtain measurement information in real time, and you can use the method of sequential polling of sensors. This approach will make it possible to reduce the heating of the ESP-32 module, which will result in higher durability of the measuring tool. Considering the fact that the dew point occurs mainly near the metal walls of the silo, the humidity of grain near the wall areas increases, and this results in the temperature increase, and the rotting process begins. Thus, it makes sense to conduct more frequent polling of sensors that are in contact with the silo walls. Theoretical calculations have shown that for three polls of sensors located in the wall area, one poll of sensors located inside the silo is enough.

After the polling, the measurement information obtained from each sensor is marked with a time index and stored in the ESP-32 memory unit for 10 minutes. Then the data packet is waiting for a request from the server. In response to the request, measurement information is transmitted over a wireless secure data channel. If the required information is not received within 10 seconds, the server sends the second request to the tool of accumulating measurement information. This procedure is performed 5 times, and in case of failure, the system sends a signal about the loss of contact with the tool to operators and technologists.

Measurement information obtained from sensors in time section is stored on a local server, and its visualization is possible both on a desktop personal computer and on mobile devices that receive data through a secure channel directly from the wireless router. The temperature and humidity control system can be integrated into the silo conditioning system, and certain humidity and temperature limits can be set, at which the system will automatically turn on the turbines to dry the grain or pump it into another silo.

4. Global temperature and humidity control system of the grain storage cascade

The above-described system of grain humidity and temperature control should be used at one local site, whereas for large agricultural holdings with grain storages located in different parts of the country or in several countries, it is advisable to use the Cloud environment to analyze grain condition at different sites (Fig. 3).

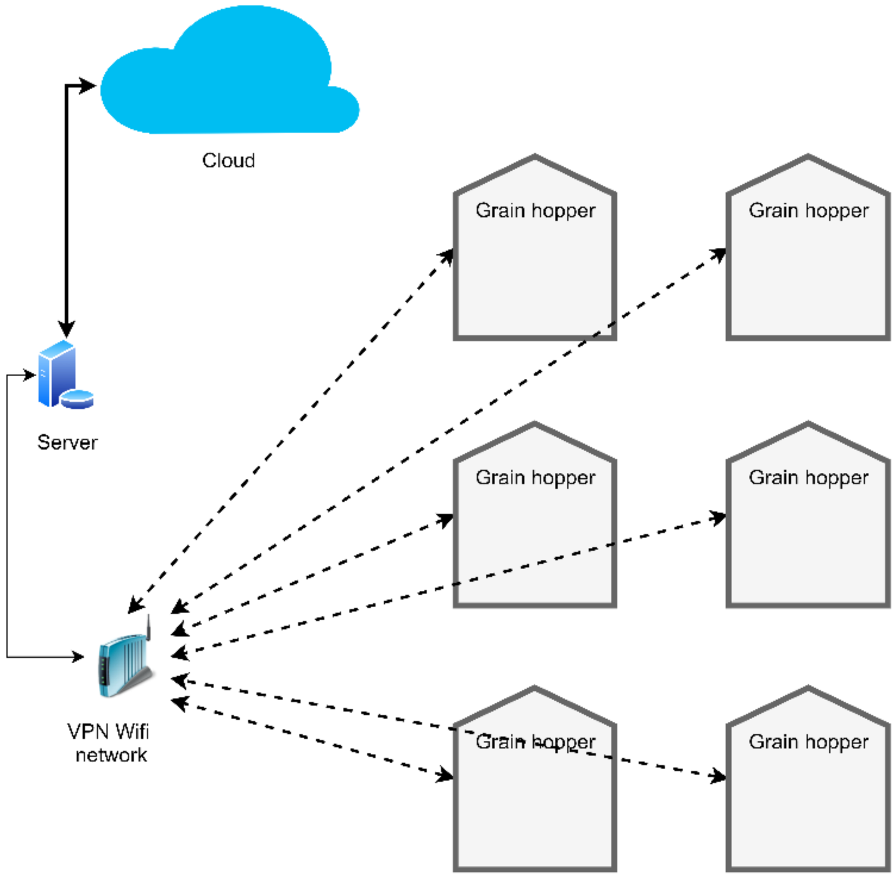

Fig. 3. Model of the global system of control over the grain humidity and temperature

The local server stores information at a 10-minute interval for each silo. There can be any number of silos within one grain storage and their quantity is limited only by the server capacity and the bandwidth of the wireless router. However, there is no point in taking such parameters into account, considering the modern technology of data accumulation and transmission. Information from each server that is responsible for a particular grain storage comes to the Cloud environment, where the data is aggregated and presented on a large scale of a set of grain storages (Fig. 4).

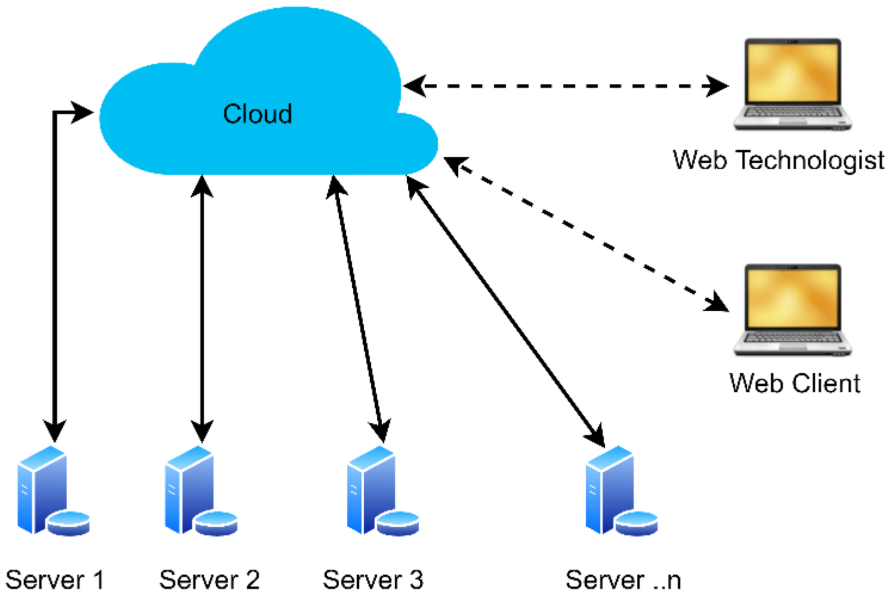

Fig. 4. Scheme of the global system of data accumulation, storage and processing

Operator or technologist of the Agro holding can analyze the changes in temperature and humidity, both in each individual silo and in the whole grain storage or grain clusters. Also, they can control the conditioning and drying systems of grain, obtain information about its quantity before supply and during storage, transfer of grain from one silo to another silo, etc. Representation of the received information is possible both by graphic and numerical methods, for user's option, which makes it possible to carry out the analysis of silos that require more active ventilation or heat insulation depending on climate conditions.

5. Software implementation of local temperature and humidity control system in the silo

The developed system is divided into several parts, namely: hardware, server, client, which in turn is divided into administrator and client parts. In this case, there is a software implementation of the local client part of the measuring system for one silo. The measuring information from the sensors is accumulated by the local system (Fig. 2), and every 10 minutes, by means of contactless secure connection, it is transferred to the server, where the data is accumulated and pre-processed. The client part (Fig. 5) of the system allows viewing the following data received from the server:

- grain temperature in a particular silo, in degrees Celsius;
- grain humidity in a particular silo, as a percentage;
- loading of the silo with grain, which is measured in thousands of tons;
- graphical representation of temperature changes with a set time frame;
- emergency warnings in the temperature and humidity control system.

The management system on the client's part includes:

- control of conditioning and grain purging systems inside the silo;
- control of the system of pumping grain from one silo to another silo.
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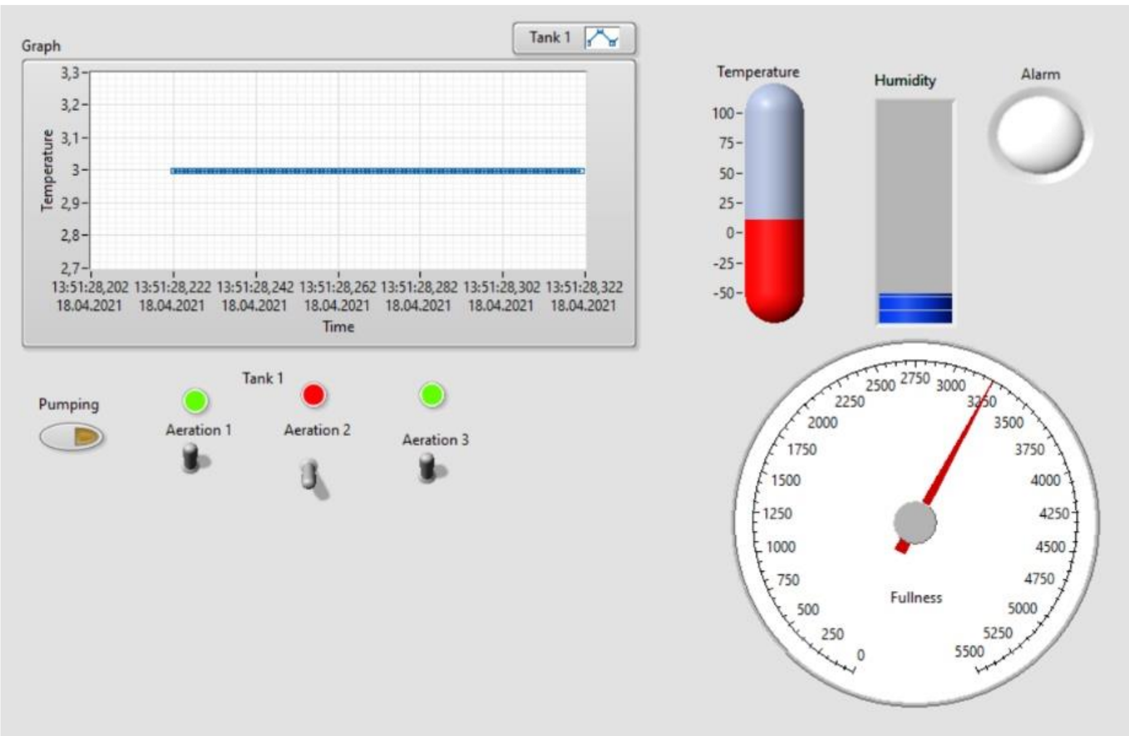

Fig. 5. Appearance of software implementation of the client part of the temperature and humidity control system in the silo

It should be pointed out that the allowable temperature and humidity limits inside the silo can be set from the administrator control panel, represented by the technologist. Within these limits, the system will automatically control the temperature and humidity, and if at least one indicator crosses the set limit, the ventilation system is automatically turned on. If during the time set by the technologist the temperature does not drop, the system signals to the operator and the technologist, and they decide whether to pump the grain or continue ventilation.

6. Conclusions

Both large and smaller Agro holdings are advancing to storing grain in grain storages of silo type. This is due to low price and simplicity of construction of such elevators, as well as their mobility and the speed of assembling metal structures. However, their advantage is partly their vulnerable point, as the thermal conductivity of metal is much higher than that of concrete or brick. Therefore, there is a need to control the temperature and humidity inside the silo. The developed system allows accumulating and transferring data from local tools to the server, and to carry out the detailed analysis of temperature and humidity changes at any moment of time and react automatically to the change of any parameter.

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