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DEVELOPMENT OF AN INTELLIGENT CONTROL AND MONITORING SYSTEM FOR A CONVEYOR DRYING UNIT PROTOTYPE BASED ON ARDUINO UNO R3

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This paper presents the design and experimental validation of a working prototype of an automated control system for a conveyor drying unit intended for processing bulk agricultural by-products – specifically post-distillation grain stillage. The prototype is built on the Arduino Uno R3 and integrates a DHT11 humidity and temperature sensor, a 28BYJ-48 stepper motor with a ULN2003 driver, an LCD 1602 display connected via a direct 4-bit parallel interface, and an analog potentiometer. A millis()-based algorithm enables simultaneous conveyor motion and sensor polling. A two-position controller activates heating when the temperature drops below 30°C.

Post-distillation grain stillage – the primary waste stream of alcohol production – is a valuable animal feed raw material, but its high initial moisture content (85–92%) makes direct use impractical. Drying reduces moisture to a stable 10–12%, yet the process is sensitive to variations in raw material properties [1]. High sugar content causes caramelization and stickiness at high temperatures, altering thermal conductivity and making fixed-speed conveyors inefficient. Static speeds lead to either case-hardening or energy waste as moisture fluctuates. This work aims to develop an adaptive control system that optimizes conveyor speed via real-time sensing.

The real filtration drying unit for stillage and the influencing parameters of the process are presented in Fig. 1, which shows:

1 – is the belt conveyor; 2, 3 – is the vacuum chamber for pressure reduction with a perforated surface; 4 – are the rollers supporting the belt conveyor; 5 – is the drive drum; 6 – is the receiving hopper for incoming raw materials; 7 – is the vibrator; 8 – is the mixing and feeding screw; 9 – is the drying chamber; 10 – is the brush for cleaning the belt conveyor; 11 – is the hopper for dried material.

Taking into account the parameters influencing TP and the regulated constant value of the initial moisture content of the raw material w_0^c ≈73%, the neural model of drying process can be presented as follows

$$v_{conv} = F(T_1, v_{t.a.}, w^c, H), \quad (1)$$

where the following are taken as adjustable/variable parameters:

w^c – is the final moisture content of raw materials (task), kg H_2O/kg dry raw materials; T_1 – is the initial temperature of the thermal agent, °C; $v_{t.a.} = v_0$ – is the thermal agent supply velocity at the entrance to the drying zone, m/s; H – is the height of the layer of raw materials being dried, m

A number of experimental studies were conducted in the MathLab environment with the number N of neurons in the hidden layer and different activation functions (AFs): $tahn, sigmoid, gbr$. The analysis of the learning process and testing of ANN architectures was carried out using four statistical error estimates (Dietterich 2000): absolute average relative deviation (AARD%), root mean square error (MSE), root mean square error (RMSE) and correlation coefficient R^2. As a result, the ANN structure 4-11-1 with $sigmoid$ AFs was selected and trained on 80% randomly selected training data as recommended in (Fan et al 2017). The accuracy of the model R^2 = 0.9449 on the test data set consisting of the remaining 20% of the general dataset was reached.

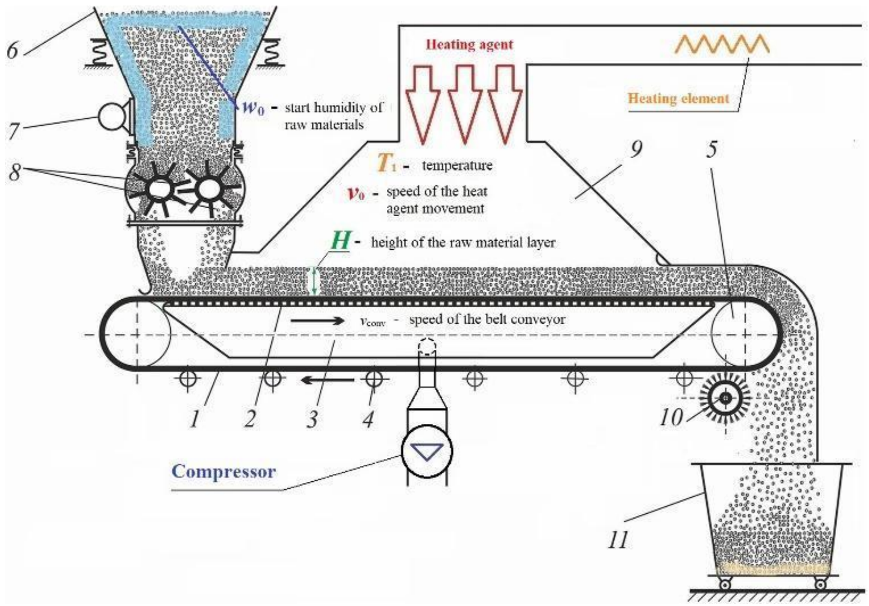

Figure 1 – Installation of filtration and drying equipment (prepared by the author)

Drying quality depends on three variables: conveyor speed (must decrease proportionally when input moisture exceeds 65%), exhaust humidity (saturation halts evaporation), and outlet humidity (must be controlled to prevent re-absorption and clumping) [1]. Layer thickness further complicates control: a thick layer creates a vertical moisture gradient causing surface overdrying while the interior retains moisture [2]. A comparative analysis of automation approaches – industrial PLCs, specialized microprocessor regulators, variable-frequency drives, and open microcontroller platforms – concludes that Arduino Uno R3 is optimal for prototype development due to its native DHT library support, interrupt-driven PWM for smooth motor control, and full algorithm modifiability without hardware redesign.

The platform centers on Arduino Uno R3 (ATmega328P), providing 14 digital I/O pins, 6 analog inputs, and hardware interrupt support. The DHT11 sensor on pin

A1 delivers digital humidity (20–90%, ±5%) and temperature (0–50°C, ±2°C) readings immune to electromagnetic interference from the stepper driver. A 10 kΩ potentiometer on pin A0 provides 1%-resolution speed setpoint input via the 10-bit ADC. The 28BYJ-48 stepper motor was chosen over DC alternatives for its maximum torque retention at the very low speeds required for viscous stillage – a regime where DC motors lose power and risk stalling. The ULN2003 driver amplifies logic signals to 500 mA per channel with back-EMF protection. An LED with current-limiting resistor simulates heater activation. The LCD 1602 uses direct 4-bit parallel connection (pins D2–D7), eliminating I2C latency during intensive motor operation.

The adaptive speed algorithm linearly maps the potentiometer ADC reading (0–1023) to a step delay of 2–20 ms, where 20 ms provides minimum speed for high-moisture drying and 2 ms provides maximum speed for dry product transport. The main loop prioritizes the conveyor drive, executing a stepper commutation step each iteration when the potentiometer exceeds a 15-unit deadband. Non-blocking DHT11 sampling runs every 2000 ms via millis() without halting the motor. A two-position controller activates heating below 30.0°C. If the sensor returns NaN, the system triggers a fail-safe (heating OFF), displaying an error on the LCD and logging it to Serial. Custom Cyrillic bitmasks for «VOLOZH» and «TEMP» labels are pre-loaded into LCD CGRAM during setup() for a Ukrainian operator interface.

Testing over 12 minutes produced 16 logged records. Humidity ranged 37–40% and temperature 25.6–26.2°C (total variation 0.6°C), confirming measurement stability and absence of stepper-induced interference. All temperatures remained below 30°C, keeping the heater continuously ON and verifying the thermal contour logic. Two system resets both resulted in full reinitialization within 2 seconds. A DHT11 communication failure correctly triggered the fault-detection response: outputs set to «Err» and heater switched to safe OFF state – directly validating the safety architecture. Future development directions include replacing DHT11 with the higher-accuracy DHT22, adding Wi-Fi remote monitoring, implementing PID temperature control, integrating an ultrasonic layer-thickness sensor for fully adaptive speed regulation. The development of pilot was completed within the framework of the European Union's Horizon 2020 program: project INITIATE (grant № 101136775).

References:

1. Huzova, I.O., Khanyk, Ya.M. Hydrodynamics of the filtration drying process of dispersed materials // Bulletin of the State University "Lviv Polytechnic": Chemistry, technology of substances and their application. – Lviv: State University "Lviv Polytechnic". – 2000, No. 414. – P. 168-172.
2. Filtration drying. Hydrodynamic resistance of a polydisperse layer of granular material // Chemical Industry of Ukraine. – 2004, No. 6. – P. 47-51.