DOI: 10.46793/SBT28.365L

MICROCONTROLLER CONTROL SYSTEM FOR A CONVECTIVE DEHYDRATOR

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Abstract: A microcontroller control system for a convective dehydrator has been developed. The IoT-class microcontroller provides control of the dehydrator, monitoring of the dehydration process, and transmission of telemetry data to the cloud service. Telegram bot is used as a cloud service. High-precision MEMS sensors BME-280 are used. To improve the accuracy, a mutual calibration procedure was implemented. Monitoring the air absolute moisture at the outlet of the dehydrator allows you to control the drying process in real-time. Telemetric information collected in the cloud service for the entire dehydration procedure is suitable for research and modeling of convective dehydration processes.

Keywords: convective dehydration, automatic control, microcontroller, cloud technology, MEMS sensors

Introduction

Automation is a natural process in the development of social production. To date, the issue of increasing the degree of automation in the dehydration of agricultural and pharmaceutical raw materials is relevant. The main problems in this area:

- high energy consumption during convective drying;
- lack of possibility of operational control of the dehydration process;
- duration of the process of convective drying to "constant mass", with possible overdrying

To achieve optimal temperature-time conditions of dehydration, it is necessary to be able to monitor and control dehydration parameters in real-time.

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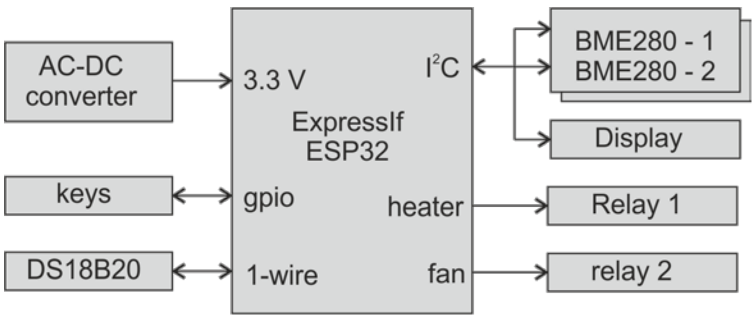
In this regard, there is a need for a device that automatically monitors and controls the dehydration process.

The aim of the work is to improve the quality of dehydrated products and reduce their cost by increasing the controllability and observability of the dehydration process and the possibility of using optimal energy-saving dehydration algorithms.

Work on the creation and improvement of control systems is carried out widely and everywhere. Modern industrial microprocessor control systems are described in (Kihara, 2020), (Dehydrator Automation System 2023). The laboratory control system is described in (Honorato, 2021). The design of control systems, conceptually close to the proposed one (but differing in implementation details) is given in (Oluwaleye, 2022), (Basista et.al., 2022).

Materials and methods

The structure of the control system is given in Figure 1. Dehydrator control system based on IoT-class SoC microcontroller ESP32 by ExpressIf Company (Espressif Systems, 2023). Such a conroller was selected due to the availability, wide set of digital interfaces, sufficient performance, low energy consumption, and the availability of two wireless interfaces: WiFi and Bluetooth.

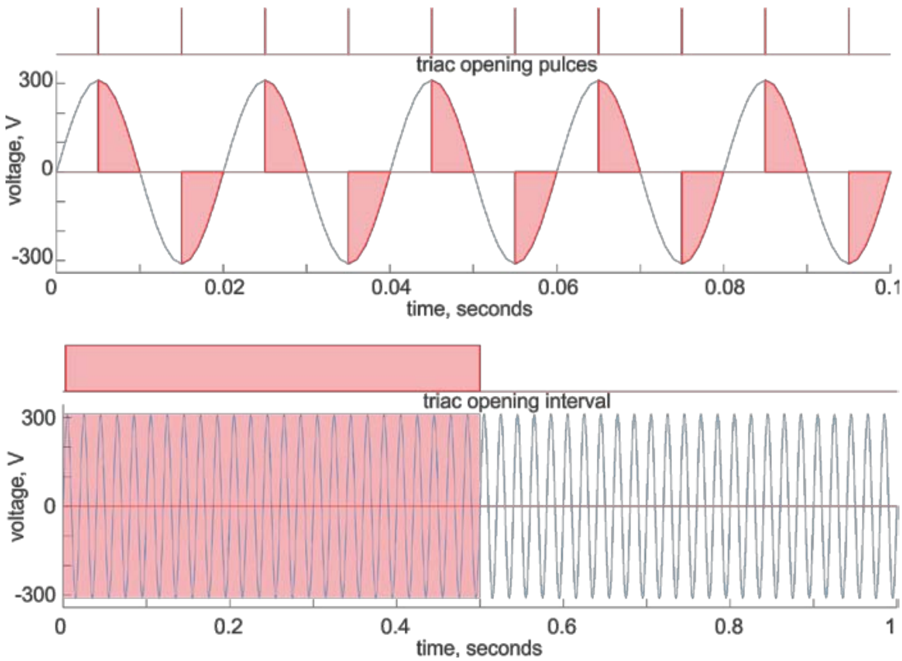


Graph 1. The structure of microcontroller-based dehydrator control system

The most significant, for understanding the features of the operation of the control system, in the structure in Graph 1 are the temperature sensor DS18B20, heater relay, and temperature, humidity, and pressure sensors BME280 (BME280, 2022). Let us dwell on their purpose in more detail.

The set "temperature sensor - heater triac relay" provides regulation and maintenance of the set air temperature at the outlet of the dehydrator heater. The formation of the control valve on the heater relay is carried out by a digital PID - controller implemented programmatically on the microcontroller. Due to the rather large inertia of the heater, no pulse-phase control is implemented, but pseudo-PWM control (Graph 2), that is, switching on the relay for a given period with a period of 1 second. During the time the relay is turned on, a part of 100 half-period of alternating current oscillations passes to the heater, and thus the temperature is adjusted with a resolution of 1:100. Such a solution does not require synchronization of the regulator operation with the network oscillation frequency, which simplifies the circuit.

For more precise tuning of the PID controller, a mathematically developed and identified model of the heater was used, and the procedure for selecting the PID controller coefficients was carried out.



Graph 2. Pseudo-PWM principle in dehydrator heater control (bottom) compared to pulse-phase control (top)

The second feature of the presented control system is the differential calculation of absolute air humidity. For this, two BME280 MEMS sensors are used, one of which measures the air parameters at the inlet to the dehydrator, and the second at the outlet. According to the formula for saturated steam pressure versus temperature

(Buck research instruments, 2012) (Eq. 1) and the formula for absolute moisture content (Eq. 2), the value of absolute moisture content for the inlet and outlet flows is calculated.

$$p_s(\vartheta) = 6.1121 \cdot e^{\left(18.678 - \frac{\vartheta}{234.5}\right)\left(\frac{\vartheta}{257.14+\vartheta}\right)} \tag{1}$$

$$W(\vartheta, h) = 622 \cdot \frac{h \cdot p_s}{p_{atm} - h \cdot p_s} \tag{2}$$

where ϑ - air temperature, p_s - saturated steam pressure, h - relative humidity. Then ΔW - the difference between the absolute moisture content of the output W_{out} and input W_{in} air is calculated, and this value is used as a characteristic of the intensity of the dehydration process (Eq. 3):

$$\Delta W = W_{out} - W_{in} \tag{3}$$

Processes with two characteristic periods are implemented in the control system. A period of one second is used to control the heater: reading the temperature sensor, generating a control voltage, and transmitting it to the heater relay. A period of thirty seconds is used to interrogate air parameters sensors and transmit telemetric information about the dehydration process.

Telemetric information about the devoicing process and, accordingly, the dehydrator control commands are transmitted via two channels: via a serial port via a USB drive to a connected computer; via a wireless WiFi interface in the Telegram bot. Channels of reception and transmission of information are equal and can be used both simultaneously and separately. The transfer of information is carried out in text form in the ANSI encoding. An example of a line with information is given in Table 1.

Table 1. Format of the telemetry information transmission string

name	time	T_d	T_1	H_1	P_1	T_2	H_2	P_2	W	Rate
value	600	52.88	31.19	30.00	101000	26.16	38.83	100900	2.43	1000

It is also possible to download the entire package of telemetry information accumulated during the experiment from the Telegram bot application. It is most convenient to upload information in the "machine-readable json" format. The format of one record is presented in Table 2. The order of the information fields in the last line corresponds to the field names in Table 1.

Table 2. Message format with telemetric information when uploading from a Telegram bot

name	value
"id"	366610,
"type"	"message",
"date"	"2022-02-14T23:00:03",
"from"	"DehydratorBot",
"from_id"	"user172xxxxxxx",
"text"	"85 24.06 24.09 33.35 102376.11 24.43 27.26 102417.01 24.05 1.56 0.00 0.00"

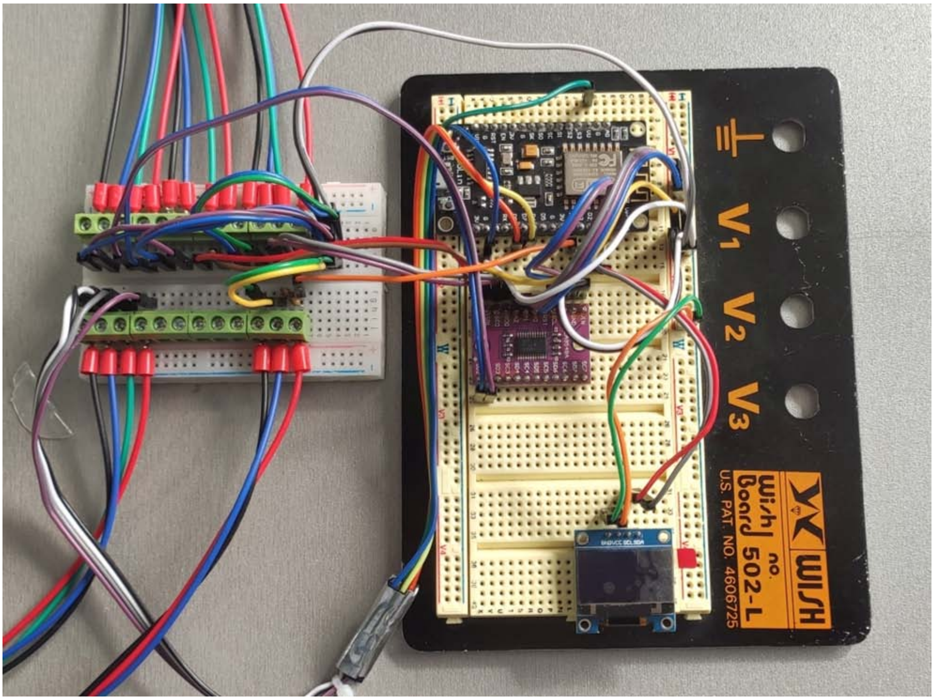
The BME280 sensor is a high-precision integrated MEMS temperature, humidity, and pressure sensor:

- humidity sensor with an error of no more than 3 % relative humidity;
- temperature sensor with an error of no more than 0.5 °C
- pressure sensor with an error of no more than 0.25 %.

Each sensor is individually calibrated after manufacture, and the calibration values are written into registers. Nevertheless, to improve the accuracy of measuring air parameters, and considering that the difference in absolute moisture content between the inlet and outlet air is of greatest interest, a procedure for mutual calibration of the BME-280 sensors has been implemented. Calibration can be initiated after turning on the dehydrator and takes about 20-25 minutes. The duration is because, after the start of calibration, it is necessary to wait for the establishment of temperature and humidity equilibrium between the calibrated sensors (which takes about 12-15 minutes) and then record 10 readings to calculate the average differential error of the sensors and write it to the memory of the microcontroller. In the future, the values are used to correct the readings read from the sensors.

Results and discussion

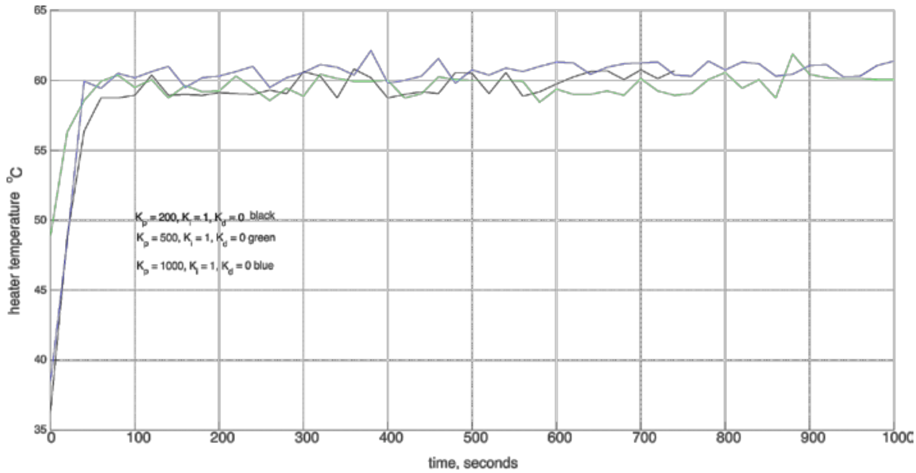
The implementation of the developed control system in the form of a layout (Graph 3) made it possible to significantly improve and expand the possibilities for conducting experimental studies on the dehydration of food products by the method of convective dehydration. Let's dwell on the achieved results in more detail.



Graph 3. The appearance of the layout of the control system

The differential calibration of the BME280 sensors made it possible to reduce the systematic error in determining the absolute moisture content from 0.7 to 0.09 mg kg^{-1} of air, which seems to be acceptable for assessing the quality of drying products.

Setting the PID controller made it possible to maintain the air temperature at the outlet of the heater with an error of no more than 0.5 °C without overshooting. Comparative graphs of temperature curves are shown in fig. 4. After tuning, the values $K_p = 1000$, $K_i = 1$, and $K_d = 0$ were chosen, which provided the entry time into the 5% control tube, equal to 40 seconds.



Graph 4. Heater PID Tuning Results

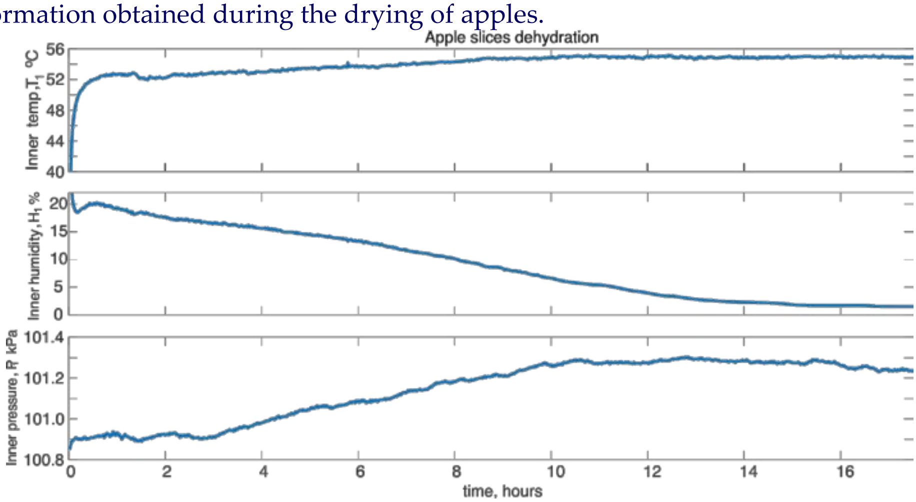
Thus, the control system provides a stable value of the set air temperature at the outlet of the heater, which will allow obtaining valid data on the intensity of the product dehydration process. At the same time, the authors have repeatedly encountered the fact that household and commercial dehydrators are equipped with relay temperature control systems operating on the interval principle, which leads to fluctuations in the air temperature after the heater, sometimes within significant limits (up to 5–10 °C).

The use of precision sensors BME280 made it possible to measure the parameters of the dehydration process with high accuracy and to calculate several derived quantities, first of all, such an invariant as the absolute moisture content of the air.

The system was tested by dehydrating apple slices in a modified household dehydrator (Graph 5).

Figure 5. A modified household dehydrator (left) and a tray of dehydrated apple slices (right)

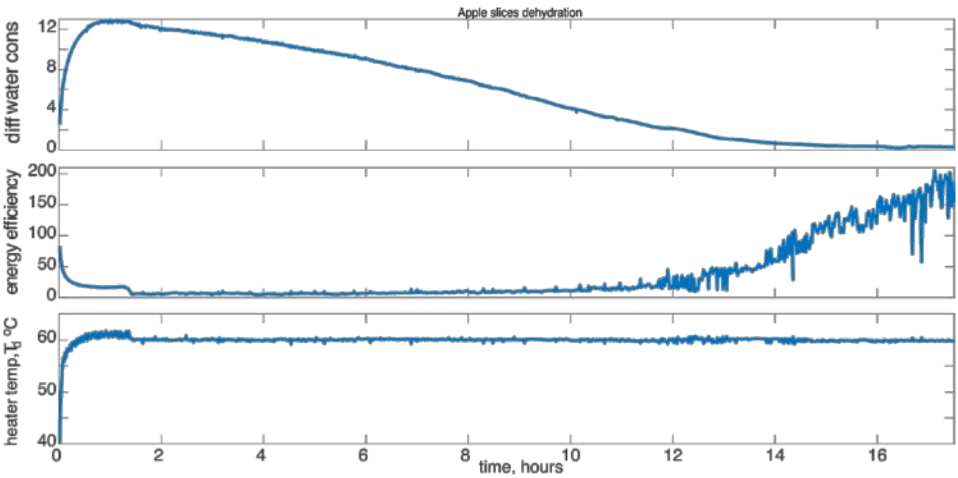
The following graphs (Graph 6) show some channels of telemetric information obtained during the drying of apples.



Graph 6. Graphs of telemetry information from the first (internal) BME280 sensor. From top to bottom: temperature, relative humidity, pressure

Fig. 6 shows graphs of temperature T1, relative humidity H1, and pressure P1 recorded during a complete dehydration cycle of apple slices. The duration of the process is 17 hours, and the air temperature of the heater is 60 °C. The graph of temperature and humidity shows that as the product dries out (decrease in the relative humidity of the air at the outlet of the dehydrator), the temperature of this air increases. In general, this means that a smaller proportion of the energy brought by the air from the heater is spent on the evaporation of moisture from the product. The pressure graph shows that even during one drying cycle, the pressure can change quite noticeably for precision measurements (0.5 %), which is desirable to take into account when calculating the absolute moisture content.

However, more informative, for the analysis of processes during drying, are graphs of derived values (Graph 7; diff water – mg_{H20} kg^{-1} of air, energy costs for drying – W of power to remove 1 mg_{H20} kg^{-1} of air, and as a reference value – the air temperature at the outlet of the heater).



Graph 7. Graphs of absolute moisture content

Graph 4 allows us to formulate criteria for controlling the dehydration process. For example, it is possible to stop the drying process upon reaching a certain value of the moisture content in the air stream. Or by the loss of a certain amount of water by the product. Or by exceeding a certain threshold by energy costs, etc. Also, the collected telemetric information provides rich material for the development of mathematical models for drying products, for ex: (Filipović, 2021). But the issue of modeling is beyond the scope of this article.

Currently, the second exemplar of the control system is being assembled and adjusted for use in the Food laboratory of the Faculty of Agronomy in Cacak, University of Kragujevac.

Conclusion

The presented system of microcontroller control of the dehydrator makes it possible to control and monitor the process of dehydration of food products in a convective dehydrator in automatic mode, with the output of telemetric information to a local computer or a cloud service. The measurement time is not limited. The high accuracy of the measurements made it possible to successfully calculate such an invariant as the absolute moisture content of the air. The received telemetric information can serve both for offline analysis to study and model dehydration processes and for the operational management of the dehydration process.

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