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Artificial Intelligence Assisted Technologies for Controlling the Drying of Fruits and Vegetables using Physical Fields: A Review

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Abstract: *Artificial intelligence (AI), which is considered by ability to learn and adapt continuously, can enhance the fault tolerance and robustness in process control. Application of high-efficiency physical fields such as microwave, radio frequency, infrared radiation and ultrasonic fields can result in efficient production of dried fruit and vegetable products with high quality. Whether the combination of AI technology and efficient physical field can obtain better dried products of fruits and vegetables, and how AI can be applied in the drying process of fruit and vegetable, has attracted extensive attention*

Keywords: Artificial intelligence

I. INTRODUCTION

Drying is the most commonly used food preservation technique, which extends shelf life by lowering water activity, and reduces the mass and cost of transportation (Zielinska, Zapotoczny, Alves, Eikevik, & Blaszczak, 2013). Common conventional drying techniques include hot air drying (HAD), vacuum drying (VD) and freeze drying (FD). Each drying method has different advantages and disadvantages(Q. Sun, Zhang, & Mujumdar, 2019). For example, the high temperature and long time drying of air drying (AD) will greatly reduce the content of vitamin C and chlorophyll in the dried samples, and will cause large shrinkage and poor water replenishment(Qing-guo, Min, Mujumdar, Wei-hua, & Jin-cai, 2006). The FD technique allows retention of the original flavor of the fresh food, but it consumes a lot of energy. The VD technique can reduce the oxidation degree of foods, but it is not economical. Because fruits and vegetables contain a large amount of water, the conventional drying technology will cause uneven and excessive during the drying process, resulting in the structural destruction of fruit and vegetable. This affects the taste and loss of nutrients of the dried products, which is difficult to meet the requirements of the product. If the drying process can be well analyzed and controlled, the dried product with high edibility and nutritional value can be obtained. AI technology is being applied in many fields and developing continuously. Navickas et al. study on logistics cluster can improve the information sharing, improve the accuracy of prediction, and benefit the management of urban food supply chain(Gružauskas, Gimžauskienė, & Navickas, 2019). Alireza et al. proposed a general model to predict the viscosity of nanofluids using adaptive network-based fuzzy inference system (ANFIS) (Baghban, Jalali, Shafiee, Ahmadi, & Chau, 2018). Sina et al. reported that computer intelligence (CI) can be used in qualitative analysis of hydrogen production process(Faizollahzadeh Ardabili et al., 2018). Rapid advances in digital technology and software have enabled AI to be applied to the most existing drying technologies with many benefits (A. Martynenko & Bück, 2018). AI can optimize and control the drying process and improve the quality of dried products, which is an advantage that traditional drying does not have(K. Erenturk, 2009).

Using high quality and high efficiency new drying technology to dry fruits and vegetables is the development trend of fruit and vegetable drying(M. Zhang et al., 2017). Using combined drying techniques or drying techniques assisted by physical fields such as microwaves, ultrasonic fields can overcome the problems of uneven drying, large energy consumption and nutrient loss. Compared to the conventional drying techniques, the development of combined drying techniques assisted by high efficiency physical fields shows many advantages. Microwave-assisted drying has the following advantages: good product quality, short drying time, and flexible production of a variety of drying products

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with good efficiency(M. Zhang, Tang, Mujumdar, & Wang, 2006). Zhang et al. have successfully combined microwave, infrared, radio frequency and other physical fields with drying technologies to dry fresh fruits and vegetables; they solved the problem of uneven and low efficiency in drying(Min Zhang, Jiang, & Lim, 2010). Hot air-assisted radio frequency drying (ARFD) technology can evenly dry fruits and vegetables and reduce the drying time(Roknul, Zhang, Mujumdar, & Wang, 2014). Pulse-spouted microwave vacuum drying (PSMVD) can overcome the disadvantages of high energy consumption in freeze drying (FD) and the non-uniform drying of microwave freeze drying (MFD) (H. Jiang, Zhang, Mujumdar, & Lim, 2014). The products dried by PSMVD show high elasticity and high hardness(Yuchuan Wang, Zhang, Mujumdar, & Mothibe, 2012). Lv et al. used a variety of different drying technologies assisted by physical fields to dry edamame, such as hot-air drying (AD), pulsed jet microwave vacuum drying (PJMVD), vacuum infrared drying (VID) and microwave drying (MD). They found that the dried edamame by PJMVD had the shortest drying time, and the smallest color difference compared with the fresh edamame. In addition, the PJMVD edamame had better quality properties including lower beany flavor, more uniform microstructure, better swelling effect and brittler characteristic(Lv, Zhang, Bhandari, Yang, & Wang, 2017).

Fruit and vegetable drying is a complex process that is difficult to control since it is necessary to control several indicators during drying process. Fruits and vegetables contain a lot of water and nutrients, which may be lost during drying. So, we need mathematical modeling to help us understand the drying process and improve the quality of dried products. However, drying is a complicated, nonlinear and dynamic process. Often the basic mechanisms of heat and mass transfer of complex food materials are not well understood(Q. Sun, Zhang, Mujumdar, & Yang, 2019). Using mathematical, statistical, numerical and analytical techniques to determine the relationship between the input and output of the drying process is cumbersome or even impossible(Aghbashlo, Mobli, Rafiee, & Madadlou, 2012). However, some artificial intelligence technology has excellent built-in algorithm and learning ability, which can solve the non-linear modeling problem in the drying process and optimize the control of the drying process (Aghbashlo, Hosseinpour, & Mujumdar, 2015). Artificial intelligence drying, which is a promising innovative drying technology, can accurately control the drying process, and improve the quality of dried products through reliable sensors, analysis tools and computer control systems (R. Moscetti, S. Massaro, D. Monarca, & M. Cecchini, 2019). In the era of artificial intelligence, it is possible to apply artificial intelligence to the drying process of fruits and vegetables to solve the problems of uneven drying, loss of nutrients, reduction of edible value and destruction of flavor substances in the drying process.

AI is basically an intelligent machine with stable, robust, strong learning and analytical capabilities, as well as adaptive capabilities that has been applied successfully to many areas in sciences and engineering. AI combines science and technology which includes cloud computing and big data to analyze and deal with complex dynamic nonlinear phenomena. Dai et al. put forward a genetically optimized inverse model proportional–integral–derivative (PID) controller based on support vector machines for regression algorithm. It is named the GO-SVR-IMCPID controller, which can control the nonlinear grain drying process very well. Compared with other controllers, it has good robustness(Dai, Zhou, & Wu, 2020). The application of AI technology and scenarios can complete the modeling, analysis, detection and key point control in the process of fruits or vegetables drying. AI can also be used to determine optimal drying conditions while reducing costs and improving product quality (A. Martynenko, 2017). Yan et al. also used artificial neural network (ANN) to analyze the relationship between ultrasound conditions and anti-glycosylation activity(Yan, Lee, Kong, & Zhang, 2013). This paper first introduces the application of artificial intelligence technology in the process of fruit and vegetable drying, including sensor technology, computer vision system and other artificial intelligence technology. Afterwards, the drying technology of fruits and vegetables based on physical field (microwave, radio frequency, infrared and ultrasonic) was introduced. This paper discusses how the artificial intelligence technology can assist the efficient physical field to control the drying of fruits and vegetables, and what problems can be solved in the process of efficient physical field drying by different artificial intelligence technologies. Finally, some suggestions on the future demand and opportunity of AI assisted food and vegetable drying technology is put forward.

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Overview of Artificial Intelligence

Artificial neural network

ANN is a theoretical mathematical model of human brain activities and consists of a number of linear or nonlinear processing elements, also called nodes, which are interconnected through weighted connections such as the models showed in Figure 1. Generally speaking, ANN contains 3 parts of the input layer, the hidden layer and the output layer and is typically specified by architecture, learning algorithm and neuron model, in which architecture represents the interconnection pattern between the different layers of neurons, learning algorithm is for updating the weights in order to correctly model a particular task and neuron model defined by activation function is to transform a neuron's weighted input to its output activation (Samatin Njikam and Zhao 2016). In general, the ANN model can be divided into feed-forward neural network and feed-back neural network according to the type of neural network architecture and learning with teacher (supervision) style and learning without teacher (no supervision) style according to the learning style (Shi 2009).

Feed forward neural network is organized in three or more layers, an input layer, an output layer, and one or more hidden layers. From the input layer to the output layer, the network is one-way connection. Only the two neurons in adjacent layers connect each other. There is no connection between the neurons at the same level and connections between the neurons do not form a directed cycle. So the received signals from the upper layer are only sent to the next layer of neurons and there is no feedback between the neurons (Fuangkhon 2017). Typical feed forward networks mainly include Multi-layer Perceptron (MLP), error back propagation network (BP), radial basis function neural network (RBF) and learning vector quantization neural network (LVQ) (Shi 2009). Most feed forward networks are learning networks, which are more suitable for pattern recognition, prediction, classification and evaluation. For example, two separate one-hidden-layer BP-trained MLP ANN models for data smoothing and quality modeling and two dynamic RBF ANN models for moisture content and temperature modeling were proposed to estimate the drying kinetics and quality index in the fluidized bed drying process of fresh green peas, diced potatoes, and silica gel saturated with ascorbic acid (Kaminski et al. 1998). Mainly studying the mapping relationship between output and input and without feedback relationship between input layer and output layer, the feed forward neural network analysis and design is relatively simple. Compared with feed forward neural network, the output neurons of feedback neural network have at least one feedback loop, and the signal can flow forward or reverse. The typical feedback networks include Hopfield neural network, Boltzmann neural network and the Kohonen neural network (Shi 2009).

In terms of learning style (Shi 2009), learning with teacher and without teacher are introduced (Shi and Zheng 2006). Learning with teacher is also called supervised learning, and its structure is shown in Figure 2. The design training process is guided by teacher and gets the data selected from the application environment (a series of expected input and output data as training samples). The network connection intensity is constantly adjusted by the error between the desired output and the actual output until the satisfactory input-output relationship is reached. Under the guidance of teacher, learning neural network can adapt to the changes in the environment, but it is easy to forget the knowledge they have learned while learning new knowledge. There are teachers' learning algorithms incl uding back propagation (BP) algorithm and learning vector quantization (LVQ) algorithm etc. Compared the data of expectation and target output in the process of learning with teacher, there is no expectation data in the process of learning without teacher which can be divided into unsupervised lea rning and enhanced learning. Without teacher's guidance (expected input information) and evaluation mechanism, the neural network of unsupervised learning automatically adjusts the weight of the connection according to the input data and classifies the data with similar features according to the statistics rule in the training process. By adopting competitive learning rules, the commonly used unsupervised learning algorithms include adaptive resonance theory (ART) and Kohonen algorithm etc. Reinforcement learning (Niv and Langdon 2016; Gershman 2016) defines a small set of normative targets (accurately predicting the sum of future rewards, choosing actions that maximize reward attained etc.) and formalizes the process through which stimulus-reward predictions are acquired and used to guide choice behavior. Reinforcement learning algorithms mainly include Q learning algorithms, genetic algorithms, immune algorithms and DNA soft computing. With the advantages of online and adaptive learning capability, reinforcement learning has been a powerful strategy tool to solve optimization problems (Kara and Dogan 2018) in many fields (Miljkovi et al. 2013).

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The learning rules (Shi 2009) involve the optimization theory, calculation method and signal processing etc. In addition to the basic algorithm, learning rules can make some improvements combined with other algorithms such as genetic algorithm, simulated annealing algorithm, perturbation algorithm and particle swarm algorithm. Generally speaking, learning rules include

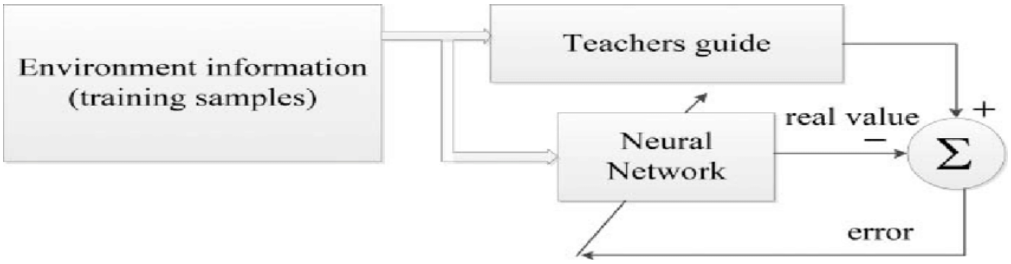

Fig: Schematic diagram of Learning with teacher

Hebb rule, Delata rule and competitive rule. As the basic learning rule of ANN, error correction learning (also known Delta d learning), is a sort of supervised learning method. The input and output are used to denote the two neurons on the two sides of one synapse, and link weight is used to denote the link strength of the synapse. The objective of the system optimization is to find the optimal weights between output and expected value by the iterative method. Hebb learning rule is a sort of unsupervised learning method and it determines the link weight of neural network according to the current input and output of system. The objective of the system optimization is to find the optimal weights between inputs and outputs by the iterative method. As the activity law of neuron, viz., if the two neurons on the two sides of one synapse are activated at the same time, the strength of the synapse will be increased, When the input and output take positive numbers, they are regarded to be activated and the link weight will be increased. The competition of neural networks means that when input mode is provided, the processing elements in a neural network will compete for the "resources", such as the output. For every input pattern, all the processing elements will generate an output. Only the "most desirable" output is adopted, and only the winning processing element is renovated. So competitive learning rule is a sort of unsupervised learning method and it can modify the link weights to adapt to the changes of the external environment by the simulation of human experience based on past experience. Compared the characteristic of Hebb learning rule, viz., many neurons could be activated at the same time, only the output layer neuron which wins the competition in processing of competitive learning is activated, and the strength of the synapse will be increased. When the input and output take positive numbers, they are regarded to be activated and the link weight will be increased, which makes competitive learning very suitable for finding statistical features of input patterns and classifying input patterns automatically. The competitive neural network generally consists of the input layer and the competition layer such as the self-organizing feature map (SOM) and counter propagation network (CPN) which are also structurally feed forward neural networks.

Fuzzy logic

Fuzzy logic (a way of AI) (Shi 2009) is mainly designed by simulating human brain's reasoning ability and decision making ability and composed of fuzzy rule base, fuzzification, fuzzy inference and defuzzification (Mohd Adnan et al. 2013). According to the working principle of fuzzy logic as shown in Figure 3, the operator's technical knowledge or expert experience is translated into forms of fuzzy rules and compose a fuzzy rule base. The precise input signal becomes fuzzy input signal after fuzzy processing. Then fuzzy input signal is dealt through fuzzy inference in fuzzy rule base to get fuzzy conclusions. After defuzzification of fuzzy conclusions, the system gives precise and specific output data

One method that creates the most useful fuzzy rules is the "IF-THEN" rule statement (Mohd Adnan et al. 2013) which has been used in PID drying Controller (Dai et al. 2017), intelligent monitoring (Tavakolipour et al. 2014), and parameter optimization (Nadian et al., 2017) etc. The fuzzification process should be concerned with two aspects, viz, fuzzy set whosegeneral way is Zadeh representation and sequence pair representationand membership function which commonly include triangle function, trapezoidal function, sigmoid function, Gauss function etc. The fuzzy inference is a method to get fuzzy conclusions by calculating the membership degree of the input to the related fuzzy sets according

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fuzzy rules and generally used the maximum and minimum synthesis regulation. The commonly used methods for defuzzification process are center of gravity (COG), central mean (CA), the maximum criterion method and the mean value method of maximum value

Expert system

Expert system (Shi 2009; Wagner 2017) is a kind of computer intelligent system with professional knowledge and experience and has the ability as well as experts to solve complex problems by the experts thinking model using knowledge representation and knowledge reasoning in AI. According to knowledge representation technology, it can be divided into logical album system, rule-based expert system, expert system based on semantic network and frame based expert system. According to objective and task characteristics of the solved problem, it can be divided into interpretation expert system, prediction expert system, diagnosis expert system, debugging expert system, maintenance expert system, planning expert system, design expert system, detection expert system, controlling expert system and educational expert system. The function and structure of different types of expert system are different, and the general form of expert system is given in Figure 4. As shown, expertsystem generally consists of 6 parts: human-machine interface, knowledge acquisition, knowledge base, inference engine, dynamic database and interpreter.

The human-machine interface is the place where system and user communicate and user inputs basic information, answers the questions raised by the system, and gets the reasoning results and related explanations. Knowledge acquisition is the key to the superiority of expert system knowledge base, as well as the bottleneck problem of expert system design. Through knowledge acquisition, knowledge base can be expanded and modified and the system realizes automatic learning function. A knowledge base is used to store the knowledge provided by an expert. The problem solving process of expert system is to simulate the way of thinking of experts through knowledge in knowledge base used to store the knowledge provided by experts. So knowledge base is an important part of expert system, the quality and quantity of which determine the level of expert system. Generally speaking, knowledge base in expert system is independent from other expert system programs so that users can change and modify the content of knowledge base to improve the performance of expert system. In view of the current condition or known information, inference engine repeatedly matches the rules in the knowledge base in order to get new conclusions and results of problem solving. Dynamic database as a temporary storage area is usually used to store the original data, intermediate results and final conclusions needed in the process of reasoning. Interpreter can make a description of the conclusion and the solution process according to the user's questions, which makes expert system more humanized and friendly

Section snippets

Sensor technology

A sensor is a detection device, which can sense and measure the information related to the sample, integrate and turn the information into electrical signals or other signals for output according to certain rules. The signal is used to control the process following appropriate algorithms.

The application of sensor technology is of great significance to artificial intelligence-assisted drying. A combination of temperature sensor and drying technology can be used to control temperature change

AI assisted highly physical field drying of fruits and vegetables

High efficiency physical field drying techniques mainly include microwave drying, radio frequency drying, infrared radiation drying and ultrasonic drying. By using these physical field drying techniques, the drying time and energy consumption of fruits and vegetables can be reduced, while the drying process, the sensory quality and nutritional value of fruits and vegetables can be improved. Physical field drying has its own shortcomings, such as uneven drying, loss of aroma, loss of nutrients

Suggestions for future work

Fruits and vegetables, which are our daily sources of vitamins and fiber, are an important part of our diet. However, it is difficult to preserve fruits and vegetables due to their perishable properties. The common curing methods will increase the unhealthy nitrite. Canned fruits and vegetables can be preserved for a long time, but there will be certain flavor changes and nutrition loss, and the production cost is relatively high. In a sense, drying is a good way to preserve fruits and

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Scope and approach

The application of artificial intelligence technology to assist the efficient physical field in the drying of fruits and vegetables is the development trend of fruit and vegetable drying industry in the future. This paper aims to provide a concise overview of recent research in the rapidly emerging area of AI-assisted drying of fruits and vegetables using physical fields to provide energy for drying process. A selection of AI technologies is introduced such as sensor technology, computer vision systems as well as a few relevant AI technologies used in the drying process of fruits or vegetables. Afterwards, it summarizes the application of artificial intelligence in the physical drying of fruits and vegetables, and how to improve the shortcomings of highly efficient physical field drying of fruits and vegetables with AI.

Key findings and conclusions

The application of high efficiency physical field in the drying process of fruits and vegetables can solve the problems of large energy consumption, uneven drying, poor sensory evaluation, and large nutrient loss. The drying process and the corresponding drying model of fruits and vegetables can be detected and controlled online, and the optimum drying scheme can be determined using artificial intelligence technology. The most important thing is to make up for the shortcomings of highly efficient physical field drying of fruits and vegetables. The artificial intelligence technology has a promising application prospect to assist the efficient physical field drying of fruits and vegetables.

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