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A Fish-Drying Control Method Based on Skilled Worker's Performance

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Abstract

In this paper, a fish-drying control method is proposed, which utilizes prediction of proper change in weight of material fish based on skilled worker's performance. The function of the proposed system is largely broken down into two procedures: The procedure before drying and the one during drying. The procedure before drying is the determination of necessary drying conditions and the required drying time. Required drying time and proper changes in weight for a specific product are obtained by using fuzzy inference and regression models. The procedure during drying is the prediction of the state of material at the end of drying, or the state of product and regulation of drying conditions to attain the prescribed goal before drying. The prediction of product is obtained by using a set of linear-differential equations obtained by the authors' previous work. Drying conditions are regulated by using fuzzy inference. A good agreement between the results of simulation and experiments is obtained, which implies the usefulness of the present control method.

1. Introduction

A skilled worker has his own way of operating his particular system. He knows what to do almost in every situation from experience. But his such idea is built in some imagerial way. So often, it is very hard even for himself to explain why it is good, in words. Knowing such characteristics of an expert of fish drying, the authors tried to acquire his ideas by mimicking and learning his ways by performing real drying using a real drying room.

The authors have proposed, in References [1,2,3], a new methodology for building a fish-drying process control system which adapts human skill. That is, first, the special techniques and knowledge for drying were discussed, which are fundamental in automating the drying process. Next, estimation of dryness of products and prediction of necessary drying time are discussed. And based on those discussions, a new type of drying room equipped with an intelligent controller was proposed and made for experimental use, which has a size available for real manufacturing [4,5].

Thus in this paper, a further development of the authors' drying room based on those preceding results is briefly described and the effectiveness of the improvement of that control system is examined through experiments for producing the mild salted and semi-dried, whole products of anchovy. Several kinds of fish are used in previous experiments. Use of anchovy is the first time, and it is employed for showing the wide applicability of the authors' system (Anchovy is more fatty than other kinds of materials ever used [6].). Through those experiments, it is also shown that the system works very well.

As mentioned above, a skilled worker's process of drying is largely broken down into:

1) Determination of drying conditions and prediction of required drying time which are made before starting drying.
2) Regulation of drying conditions during the execution of drying.

Experiments were made in order to examine the applicability of proposing drying control system.

An expert evaluates the quality of raw material such as freshness, and he tries to produce a product which is proper for that particular raw material. Hence, for the procedure required before drying, prediction of the final state of fish dryness at the end of drying, the control system must perform the followings:

1) Proper dryness for the particular material.
2) Drying conditions and drying time for the proper dryness.

Dryness of product has some range to attain depending on the quality of raw material; that is, high quality material can attain highest dryness or the most hard product. Determining a proper dryness for a specific material needs human intuition based on his experience. Here in this paper, its alternative process is built employing fuzzy inference. Raw material is, generally, divided into two classes depending on its length. A part of such inference rules are shown below:

If (LE is Small) and (FA is Somewhat Small)
and (DR is Small) then (RW is Somewhat Small)
or
. . .
or
If (LE is Somewhat Big) and (FA is Somewhat Big)
and (DR is Big) then (RW is Medium) (1)

For IF-part, total length [LE], fatness [FA], and degree of dryness [DR] is applied. For THEN-part, the fraction of the fish weight at the end of drying to its original weight before drying; i.e., relative weight at the finish [RW] is used. Thus necessary hardness of the product is obtained.

Then required drying time is predicted based on the result of the above fuzzy inference, and drying conditions to be applied at the start is determined by using multiple regression analysis. The drying conditions are temperature [TE], relative humidity [HU] and air flow rate [FL] in the drying room. The following models are the ones obtained for the mild salted and semi-dried, whole products of anchovy:

1) Class A (Total length = 80–119 mm)

$$\text{Time} = -13.447 + 0.7603LE + 5.0153FA - 101.72RW - 1.6001TE - 0.0347HU - 2.0892FL \quad (2\text{-a})$$

2) Class B (Total length = 120–190 mm)

$$\text{Time} = 56.493 + 0.0620LE + 4.4828FA - 89.02RW - 1.4154TE + 0.0049HU - 0.6152FL \quad (2\text{-b})$$

Rules (1) and Equation (2-a) or Rules (1) and Equation (2-b) is equivalent to a skilled worker's procedure of predicting adequate drying time for the quality of fish to be dried, based on his experiences. In fact, membership functions and coefficients are determined based on a skilled worker's evaluation and empirical data. Thus, an expert determines operating conditions for drying the specific fish netted before drying. Two examples will be given to clarify the explanation done so far. Table 1 shows the simulation results to infer the relative weight by applying Rules (1) and the results to estimate the drying time by applying Equation (2). High accuracy is shown in inferring relative weight (less than 0.01) and drying time (less than 0.40 h). Then drying starts using those conditions. The drying may not progress as supposed before drying. He knows this from experience and when and how to modify conditions during drying. His such procedure is part of his know-how. This procedure of his was also observed during the authors' experiment, and it is incorporated to the newly developed control system, as will be discussed in the sequel.

Table 1 Simulation results

Nature of fish body and drying conditions (Averaged)
Class A: Total length = 102.5mm, Fatness = 10.73
Degree of dryness = 3.00
Temperature = 23.0 ℃
Relative humidity = 38.5 %
Air flow rate = 2.41m/s
Class B: Total length = 164.1mm, Fatness = 10.25
Degree of dryness = 2.14
Temperature = 21.0 ℃
Relative humidity = 37.0 %
Air flow rate = 3.05m/s

Contents		Relative weight	Drying time (h)
Class A	*Experimental*	*0.508*	*24.00*
	Inferred	*0.500*	*24.34*
	Error	*0.008*	*- 0.34*
Class B	*Experimental*	*0.583*	*28.00*
	Inferred	*0.593*	*28.40*
	Error	*- 0.010*	*- 0.40*

2. Human Operator's Procedure during Drying and its Automatization

A few times, an operator gets into the drying room in order to inspect the progress of drying. And based on this inspection, he determines if it is necessary to modify the drying conditions in order to obtain the proper products. To be concrete, if the present drying progress is slower than assumed, then the drying temperature is reset at a higher temperature, or the drying time is prolonged. If faster on the contrary, then the modification is made to the opposite direction. On the average, his inspections are made three times, and each of them can be given a reason; the first two times, once at the early time of drying and once at the middle of drying, are for regulating proper drying temperature to find a desirable drying rate, and the last inspection is for the timing of finishing drying.

Automatizing the above process is made by the following means of measurement and estimation:
1) Load cell for measuring the decrease in fish weight.
2) A system of linear differential equations derived empirically for predicting the change in weight [2]. (This system of equations will be referred to as α-β solution.)

The comparisons between the experimentally obtained decrease in weight and its predicted curve of decrease are shown in Fig.1 for four different conditions of raw fish. Experimental data are plotted every four hours of drying except at 16 hours of drying as the average of some sample individuals, the numbers of samples for each group are

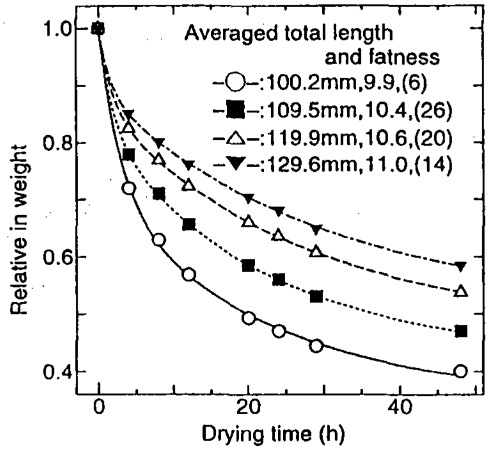


Fig.1 Comparisons between experimental data and predicted curves of relative weight with drying time
( ); Number of samples
Applied drying conditions (Averaged over 48 hours);
Temperature = 21.1 ℃, Relative humidity = 60.4 %,
Air flow rate = 3.38 m/s

indicated in parentheses in the figure. Experimental data andsolutions of the differential equations show good coincidence. In fact, the error is within 2% for every case. Hence, the system of differential equations predicts accurately the progress of drying irrespective of the kind of fish to be dried. The same procedure as mentioned with respect to an expert at the beginning of this section is employed for regulating drying conditions in the automated control system. To do this, in the present system fuzzy inference determines necessary change in drying temperature. The membership functions used are shown in Fig.2, and a part of the rules employed are as follows:

If (Distinction in predicted dryness is NB)
 and (Expansion of distinction is NB)
  then (Regulation of temperature is PB)
or
 . . .
or
If (Distinction in predicted dryness is PB)
 and (Expansion of distinction is PB)
  then (Regulation of temperature is NB)   (3)

This procedure makes drying temperature suitable for the specific fish and the desirable product. The timings and number of applications of modification of drying conditions are set depending on the progress of the drying process. Fig.3 shows speed of decrease in weight from the estimated values in Fig.1. The speed of decrease is defined to be the decrease rate per unit time in percentage.

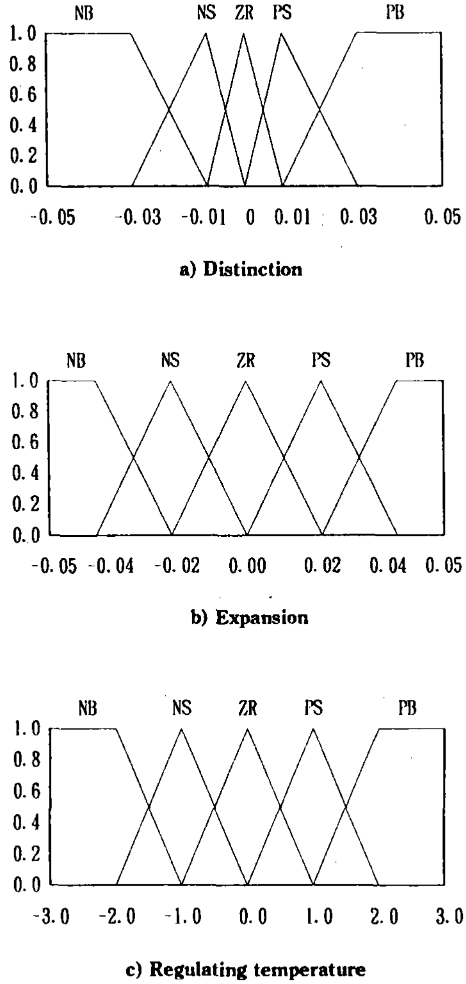


Fig.2 Membership functions

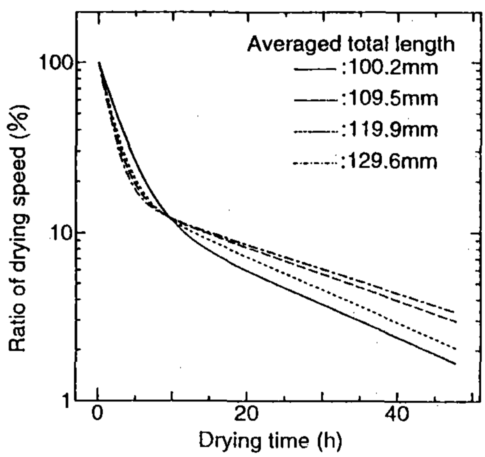


Fig.3 Changes in speeds of decrease in weight

From Fig.3, it is readily seen that the drying progresses very fast in the former stage of drying and rather slow progress in the latter stage, the boundary being 10 hours of drying. This means that regulation in each of those periods offers better drying environment. And this verifies the validity of an expert's way of regulating drying progress, already described, during drying. So in automatizing this procedure of an expert, the points of time for correcting drying conditions are set at some points in the early stage of drying and in the later stage, and at the boundary point of the early and later stages.

3. Experiments and Results

Some experiments are made in order to exemplify the effectiveness of the present idea of control. Material fish is frozen anchovy netted off the coast of Yamaguchi prefecture, and rinsed after 4 to 6 hours dipping in 4% salt water. Product is semi-dried, whole product. Table 2 shows the nature of material and drying conditions.

Table 2 Experimental conditions
Drying method; Cool-air drying

Nature of fish body	
Total length (mm)	*126.11*
Fatness	*10.29*
Expectation	
Degree of dryness	*2.90*
Drying conditions	
Temperature (℃)	*21.0*
Relative humidity (%)	*30.0*
Air flow rate (m/s)	*3.00*
Direction of wind flow	*Against*
Relative weight	*0.459*
Drying time (h)	*38.0*

Experiments were made in the newly developed drying room with an automatic controller. The elements and functions of the controller developed for the present room is shown in Fig.4. As indicated in the figure, this controller also deals with all the necessary inferences and estimations using Rules (1), Equations (2), Rules (3) and α-β solution. Degrees of dryness are denoted by the ranks in Table 3 and it is used in an expert's evaluation of dryness by visual inspction and fingering and in predicting degree of dryness by Equations (2) as the average of ranks of all individual products given in the form of Table 3, by extending ranking in a continuous form from 0 to 5. This extended use of ranking is used in Tables 1, 2, and 5.

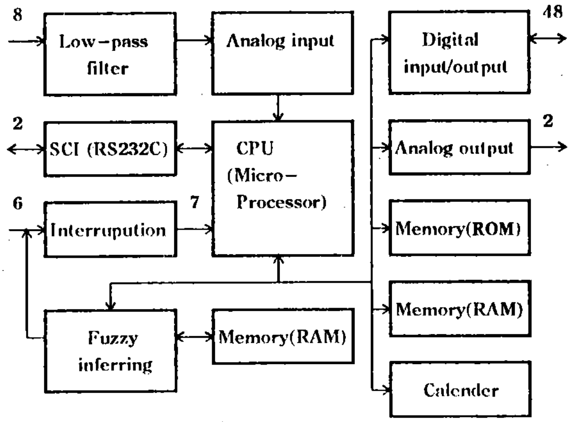


Fig.4 Elements and functions of controller

Table 3 Interpretation of ranking of expert's evaluation for degree of dryness

Rank	Evaluation	Commercial value
1	*Underdried*	*None*
2	*Slightly underdried*	*Good*
3	*Proper*	*Good*
4	*Slightly overdried*	*Good*
5	*Overdried*	*None*

Fig.5a shows theoretically determined temperaures and the real temperature transition based on those theoretical settings, and Fig.5b shows the predicted values and the measured values of fish weight decrease. It seems that measured values fluctuates more at lower temperatures. This comes from the load and the cycle of the refrigerator.

Table 4 shows an example of regulation of drying temperature during drying.

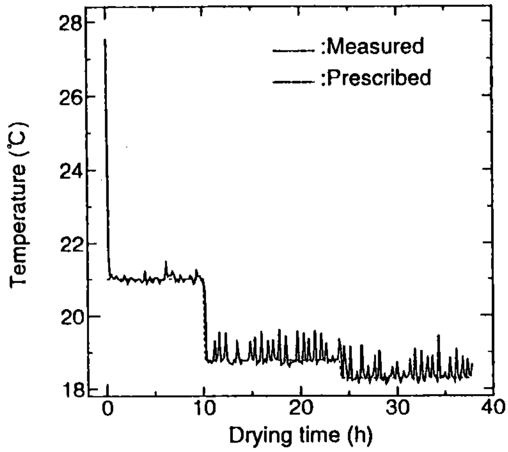
The concrete strategy is like the following:

1) First, desirable product and also necessary dryness for that specific product is determined by Rules (1) before drying. That necessary dryness is given as the fraction of the weight of product to the raw fish on average, say f0. This is the target dryness to attain by drying.

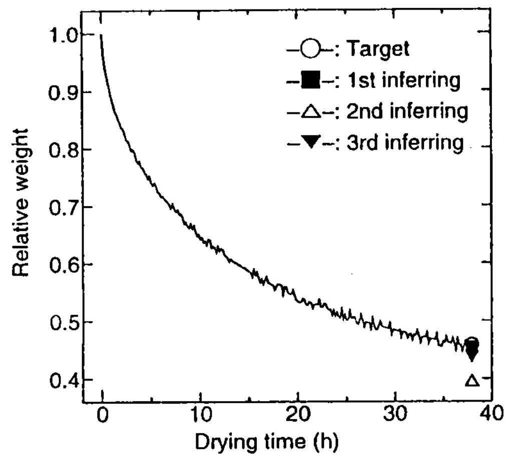
2) To check the validity of drying conditions, prediction of dryness is renewed at each observation time set at 5, 10, and 24 hours of drying during drying, by using α-β solution.

3) If there is found a significant distinction in prediction between the value f0 and a renewed prediction, then the drying condition is changed to reduce the distinction.

From 0 hours to 5 hours of drying, there is no significant distinction and no change in drying temperature is given at the point of 5 hours drying time. At the next observation time, 10 hours drying, a big distinction is found, and so temperature is decreased to 18.8 ℃.



(a) Temperature



(b) Change in relative weight

Fig.5 Results of experiment

Table 4 Regulation during drying

Time (h)	Inferred	Difference of target	Temperature (℃)
0	*0.459*	–	*21.0*
5	*0.454*	*−0.005*	*21.0*
10	*0.393*	*−0.066*	*18.8*
24	*0.439*	*−0.020*	*18.3*

Table 5 shows the effectiveness of the present drying system in the form of averaged degree of dryness. "Target" indicates the predicted dryness before drying, and "Result," the actually obtained outcome. They are in good agreement.

Table 5 The effectiveness of the authors' proposing drying system

	Degree of dryness	Relative weight
Target	*2.90*	*0.459*
Result	*2.91*	*0.455*
Error	*−0.01*	*0.004*

4. Discussion and Conclusion

A methodology for regulating drying temperature during drying is proposed. Also, the wide availability of the authors' drying system is exemplified using a kind of fish, anchovy other than those used in previous papers. Fuzzy control method used for temperature regulation during drying is found to be effective by the real experiments in the drying room developed by the authors.

Fig.6 shows the comparison of an expert's evaluation of products (in ranking in degree of dryness) made by the present method with that of products made by the conventional method. In the case of the present method, evaluation is concentrated to rank 3, while in the cases of the products by the conventional method, rankings are rather distributed. From this result, it is readily seen that quality of products is much improved by applying the present method.

In Fig.7, the overall control procedures are shown, which are based on a human expert's empirical and intuitive procedures.

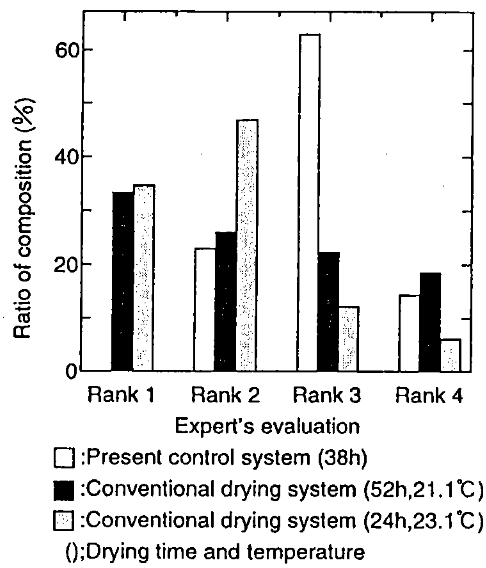


Fig.6 Comparison of an expert's evaluation

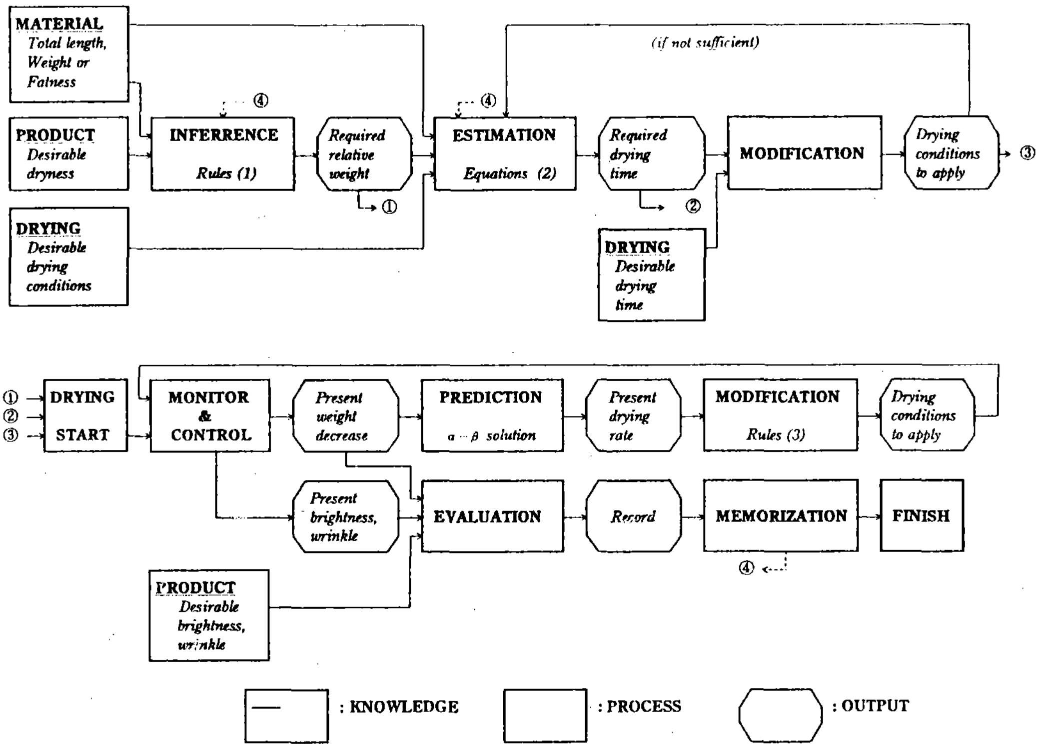


Fig. 7 Schematic of the structure of the present control method

Having the basis in the present methodology, the authors are attempting to build an intelligent decision support system for human-centered control system in order for a human operator to cooperate with an automated controller, by applying computer networking.

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