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A Study on Intelligent Fish-Drying Process Control System

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Abstract

In this paper, a fish drying process control system is proposed, which predicts the proper change with time in weight of the material fish and the drying conditions in advance, based on the performance of skilled worker. In order to implement a human expertise into an automated fish drying process control system, an experimental analysis is made and a model for the process is built. The proposed system divided into two procedures: The procedure before drying and the one during drying. The procedure before drying is for the prediction of necessary drying time. To estimate the necessary drying time, first, the proper change in weight for the product is obtained by using fuzzy reasoning. The condition part of the production rule consists of the factors of fish body and the expected degree of dryness. Next, the necessary drying time is obtained by regression models. The variables employed in the models are the factors, inferred change in weight and drying conditions. The model for the procedure during drying is also proposed for more accurate estimation, which is described by a system of linear-differential equations.

1. Introduction

Dried marine products are traditional foods in Japan since ancient periods, but the principles and techniques are not sufficiently developed excepting a few studies on the quality control [1,2]. It has been a long of time berore it attracts attention of the researchers in this field. Nowadays, most of manufacturers of these products have been suffering from a lack of hands.

Two papers on fish-drying process control were presented at the '92 KACC [3,4]. One is on the experimental analysis and expertise for the system, which make clear the requisites for automatization of the process. And the other is on the modeling and parameter estimation of the fish-drying control system. It mainly describes the procedure for the parameter estimation of a mathematical model that represents the fish-drying rate during drying. Each paper deals with the fundamentals for constructing fish-drying process control system of new type based on human like reasoning, as is shown in Fig.1.

This paper is for the facilitation of automatization in the field. Some organized experiments were performed continually in order to extract the characteristics of drying necessary in proposing such

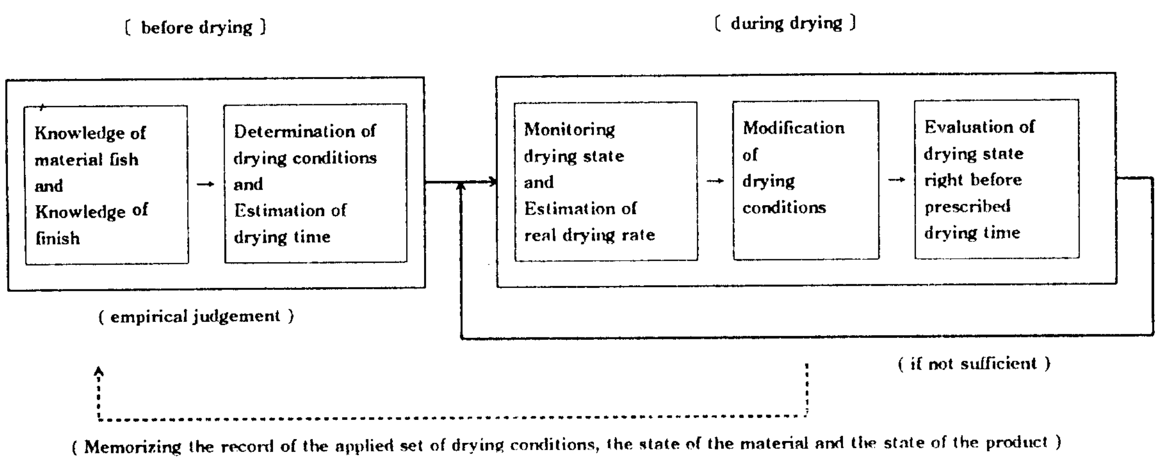

Fig.1 Schematic of the authors' proposing control system for fish drying

a new automated system for fish drying. The present paper is concerned with improvement of the control system based on the proposal mentioned above, and is so modified as to meet the above purpose. The control system consists of two procedures to produce dried marine products of good quality, which are set mimicking a human expert's way.

2. Experiments and Results

The material fish used for the present experiments are round herring which are caught off the coast of Yamaguchi Prefecture from September to October in 1992. The relation between the length and weight of the material fish are shown in Fig.2.

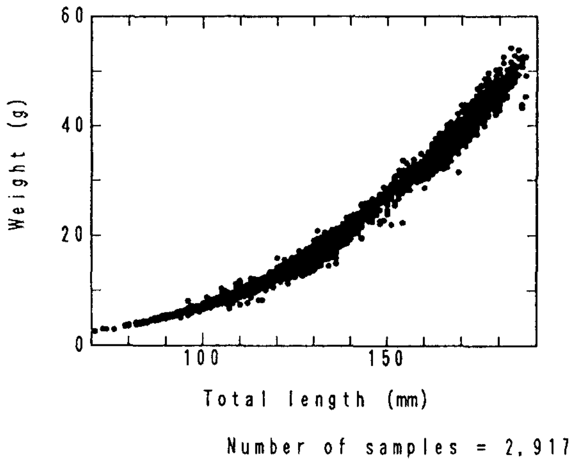

Fig. 2 Relation between length and weight

(round herring)

2.1 Component analysis

For the same species of fish, the individual difference can be recognized by the difference in size of fish body for an expert. The drying rate of material fish is affected by the size of fish body and the chemical compositions of the fish meat. The components of fish include water, protein, lipid, carbohydrates, and ash. Considering the mechanism of drying shows that water and lipid are the major components which affect the drying rate. Table 1 shows the result of component analysis. The total amount of water and lipid content is about 75g per 100g of fish weight, and there holds negative correlation (correlation coefficient = -0.778) between water and lipid as shown in Fig.3. The authors proposed a

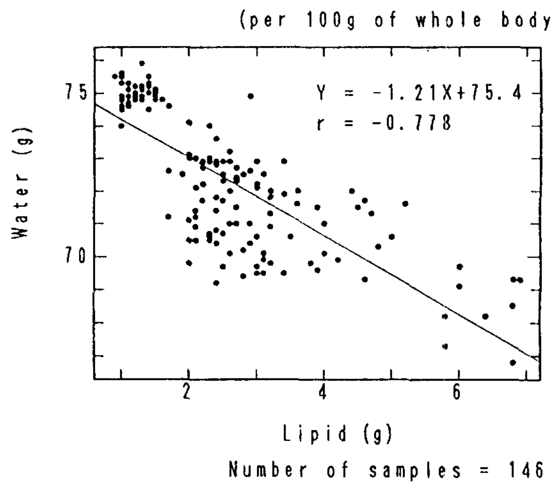

Fig. 3 Relation between lipid and water content

(round herring)

Table 1 Componets and their correlations (round herring)

Number of samples = 146

dimensions		Size of fish body			Components of fish meat (per 100g of whole body)				
		Length (mm)	Weight (g)	Condition factor	Water (g)	Protein (g)	Lipid (g)	Carbo-hydrates(g)	Ash (g)
Size and components	Average	133	20.1	12.3	72.2	19.6	2.67	0.714	4.81
	Maximum	191	60.5	14.3	75.9	22.6	6.9	1.6	7.0
	Minimum	95	6.06	10.6	66.8	17.4	0.9	0.1	2.9
Correlation coefficients	Length	1	0.978 **	0.665 **	-0.563 **	0.364 **	0.834 **	0.161	-0.366 **
	Weight		1	0.701 **	-0.534 **	0.319 **	0.853 **	0.131	-0.411 **
	C-factor			1	-0.215 **	0.0730	0.496 **	0.165 *	-0.403 **
	Water				1	-0.755 **	-0.778 **	-0.0662	-0.423 **
	Protein					1	0.422 **	-0.116	0.220 **
	Lipid						1	0.0514	-0.105
	C-hydrates							1	-0.0859
	Ash								1

* : significant at 5 % level, ** : significant at 1 % level

possible characteristic to represents the lipid content in Reference [3]; that is, Condition factor:

$$\text{Condition factor} = \frac{\text{Weight of fish x 1000}}{(\text{ Essential length of fish })^3} \quad (1)$$

where Essential length is the length of fish measured excluding caudal fin of fish. As can be found in Table 1, lipid content shows the highest correlation with the condition factor. Table 2 shows the difference in degree of correlation between condition factor and lipid content with fish length. As is clear in Table 2, the larger the length is, the higher the correlation is. So, in modeling a control system, it is important to respect this factor as the knowledge of material fish, excluding the case of rather small fish.

Table 2 Difference in correlation coefficient between condition factor and lipid content with fish length of round herring

Class (mm)	Number of samples	Correlation coefficient
100 - 119	37	0.170
120 - 139	32	0.431 *
170 - 189	11	0.866 **

* : significant at 5% level

** : significant at 1% level

2.2 Experiments

An expert determines the appropriate drying conditions and predicts the necessary drying time before drying. This procedure can be achieved by the knowledge of material fish at the time of catching and its state right before drying. The drying conditions are temperature, moisture, wind flow rate, and direction of wind flow in the drying room.

To clarify the effects on the drying rate, the following experiments were performed.

Product : Salted and dried
Drying method : Cool-air drying
Drying time : 28 hours
Conditions :
Temperature 19.0 ~ 25.0 °C
Moisture about 70 % (at the beginning)
Wind flow rate 2.50 ~ 3.50 m/s
Direction of wind flow against, follows (facing the abdomen of fish)
Judgment : Organoleptic evaluation by hand (by expert)

Rank	Expert's judgment	Commercial value
1	Underdried	None
2	Slightly underdried	Good
3	Proper	Good
4	Slightly overdried	Good
5	Overdried	None

Table 3 The results in drying experiment

Drying conditions of each experiment are as follows:
Experiment No.1 : Temperature = 19.4 ℃, Moisture = 61.8 %, Wind flow rate = 2.85 m/s
Experiment No.2 : Temperature = 22.0 ℃, Moisture = 53.1 %, Wind flow rate = 3.11 m/s
Experiment No.3 : Temperature = 25.2 ℃, Moisture = 56.2 %, Wind flow rate = 2.94 m/s

Number of experiment	Samples [average]				Change in weight with elapsed drying time						
	Length (mm)	Weight (g)	Condition factor	Number of samples	0 (h)	4 (h)	8 (h)	12 (h)	20 (h)	24 (h)	28 (h)
1	172	39.1	12.42	12	1.000	0.896	0.851	0.819	0.766	0.744	0.725
2	172	39.1	12.42	27	1.000	0.890	0.846	0.812	0.760	0.736	0.716
3	172	38.9	12.40	46	1.000	0.888	0.842	0.805	0.744	0.718	0.698
1	172	40.8	12.82	27	1.000	0.903	0.861	0.831	0.780	0.759	0.740
2	172	40.1	12.80	41	1.000	0.894	0.853	0.821	0.771	0.748	0.729
3	172	40.5	12.79	44	1.000	0.892	0.849	0.814	0.757	0.733	0.713
1	172	41.7	13.22	18	1.000	0.907	0.869	0.840	0.793	0.774	0.756
2	172	42.0	13.19	29	1.000	0.901	0.861	0.831	0.784	0.761	0.743
3	172	41.4	13.16	20	1.000	0.899	0.859	0.826	0.772	0.748	0.729

Table 3 shows an example of the result of the experiment. The average length of the samples is 172 mm. From the results of experiment, the influential factors of the process are summarized as follows:
Drying temperature is the most effective factor, and the second most factor is wind flow rate. The direction of wind flow has no effect on the drying rate.

3. System Architecture

Based on the results in Section 2, a control system for the fish drying process was built.

3.1 The procedure before drying

This is the inference process for the determination of the set of proper drying conditions and the estimation of the drying rate based on the knowledge of material fish and the past drying results obtained by an expert. Before drying, the expert decides the most suitable drying conditions according to his good amount of experience and knowledge.

Fuzzy inference and multivariate analysis are employed to predict the appropriate dryness of the products and necessary drying time during drying. Linguistic rules may be used as a fundamental model of desiring an inferential dryness of the products as follows:

If Material and Expectation then Product (2)

In this model, the variables for Material are the size of material fish, and the variable for Expectation is the degree of dryness decided by an expert. The variable for Product is the change in weight of material fish at the end of drying which is, in other words, the appropriate dryness of the product.

Using the above results, the next step is to estimate the necessary drying time. The regression models for predicting the necessary drying time before drying were built by means of multiple regression analysis as follows:

$$\text{Time} = a0 + b0...n \times \text{Material} + c0...n \times \text{Product} + d0...n \times \text{Condition} \qquad (3)$$

where a0 is a constant, b, c and d are the partial regression coefficient correspond to their variable. The variables for Material are the size of material fish, and the variable for Product is appropriate dryness of the product obtained by the above fuzzy inference. The variables for Condition are the drying conditions, such as drying temperature, etc.

3.2 The procedure during drying

Drying is executed applying the drying conditions estimated in Section 3.1 as the initial setting value for control. In the beginning of this process, the prediction of the real drying rate is predicted and correction of the drying conditions using on-line monitoring of the change in material weight is made. A fundamental model for predicting the state of fish drying, consists of linear differential equations described in Reference [4]. It is shown there that applying the (α - β)-solution makes it possible to obtain the real drying rate very accurately:

$$\frac{dx(t)}{dt} = u(t) + v(t)$$

$$\frac{dv(t)}{dt} = -\alpha \times v(t)$$

$$\frac{du(t)}{dt} = -\beta \times u(t) \qquad (4)$$

where u(t) is a constant speed that corresponds to the asymptote and v(t) is the speed with a constant rate of decrease. The real drying rate is obtained by applying Equations (4), hereby, the difference between the necessary drying rate estimated before drying and the real progress of drying is evaluated.

Next, the drying conditions are modified to control the drying rate. Basically the methodology for controlling the fish drying is similar to that for the air-conditioner by using fuzzy reasoning. The control factors are temperature, moisture and wind flow rate.

The next step is for the determination of when to stop drying and for memorizing the record of employed set of drying conditions, the state of the material and the state of the product. This step is for future better control, and corresponds to a human expert's processes of experience accumulation and knowledge acquisition. When the change in weight of material is equal to the inferred value before drying mentioned in Section 3.1, drying is stopped automatically.

4. Discussion and Conclusion

In this paper, discussed is how to construct an intelligent control system for fish drying process. A system architecture which is similar to human expert's way is proposed by modeling human expert's procedures before drying and during drying.

Fig.4 shows examples of the membership functions of linguistic rules for estimating the proper change in weight to produce the salted and dried "Wakaboshi" of round herring, and Table 4 shows the inference rules. Table 5 shows an example of the simulation results using the above linguistic rules and membership functions, and Fig.5 is the results shown in Table 5. Table 6 shows the multiple regression analysis models for predicting required drying time beforehand to produce the product. Fig.6 (a) shows the flowchart for the estimation of necessary drying time, and (b) shows the flowchart for the modification of drying conditions before drying.

Further study is necessary, but the present method makes it possible to implement a human expertise into an automated fish drying process control system.

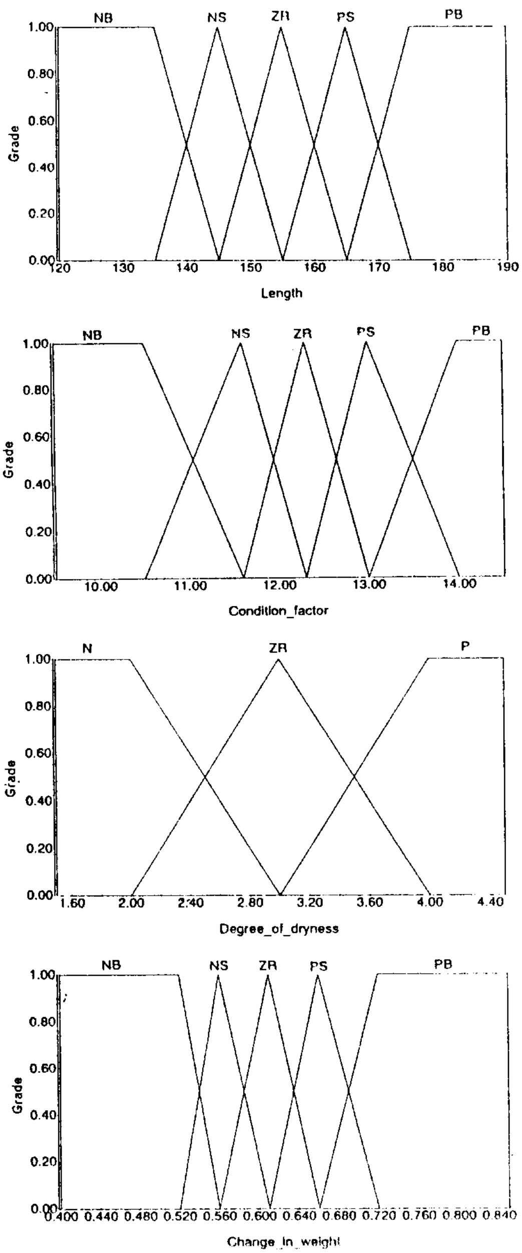

Fig. 4 Membership functions for estimating the change in weight to produce the salted and dried "Wakaboshi" of round herring

Table 4 Inference rules for estimating the change in weight to produce the salted and dried "Wakaboshi" of round herring

IF Arguments			THEN Argument
Length	Condition factor	Degree of dryness	Change in weight
N B		N	N S
N B	N B	Z R	N B
N B	N S	Z R	N B
N B	Z R	Z R	N B
N B	P S	Z R	N B
N B	P B	Z R	N S
N B		P	N B
N S		N	Z R
N S	N B	Z R	N B
N S	N S	Z R	N B
N S	Z R	Z R	N S
N S	P S	Z R	N S
N S	P B	Z R	Z R
N S		P	N B
Z R		N	P S
Z R	N B	Z R	Z R
Z R	N S	Z R	Z R
Z R	Z R	Z R	Z R
Z R	P S	Z R	P S
Z R	P B	Z R	P S
Z R		P	Z R
P S		N	P B
P S	N S	Z R	P S
P S	Z R	Z R	P S
P S	P S	Z R	P B
P S	P B	Z R	P B
P S	N S	P	Z R
P S	Z R	P	Z R
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P B		N	P B
P B	N S	Z R	P S
P B	Z R	Z R	P S
P B	P S	Z R	P B
P B	P B	Z R	P B
P B		P	P S

Table 5 Simulation results

Products	Contents	Drying time	
		24 h	28 h
Wakaboshi	Experimental value	0.683	0.662
	Inferred value	0.710	0.685
	Error	0.027	0.023
Kataboshi	Experimental value	0.347	0.329
	Inferred value	0.343	0.339
	Error	-0.004	0.010

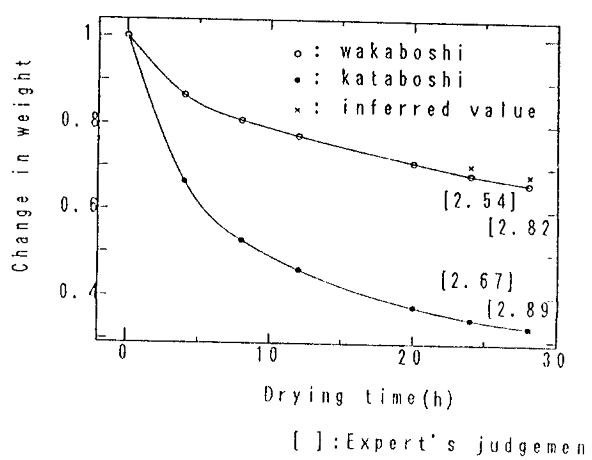
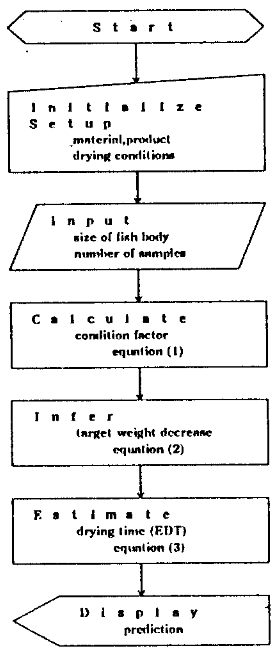


Fig. 5 Simulation results shown in Table 5

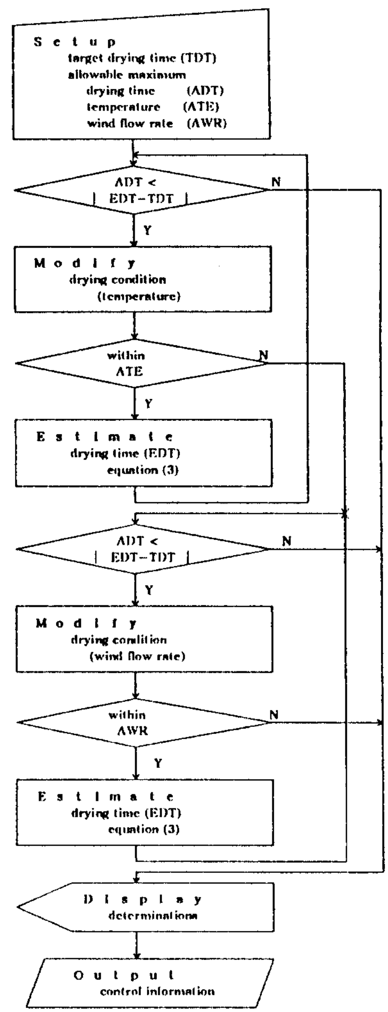
Table 6 Multiple regression analysis models for predicting required drying time beforehand

Class	Variable: Partial regression coefficient							Constant	Multiple correlation coefficient
	Length	Weight	Condition factor	Change in weight	Temper-ature	Wind flow rate	Moisture		
~ 119 (mm)	0.0338 [0.0529]	0.457 ** [0.160]	—	-36.0 ** [-0.416]	-1.40 ** [-0.418]	6.30 ** [0.261]	-0.896 ** [-0.825]	85.2 **	0.978
120 ~ (mm)	0.209 ** [1.30]	—	3.89 ** [0.633]	-56.0 ** [-2.18]	-0.654 ** [-0.500]	1.68 * [0.195]	-0.177 ** [-0.545]	-2.91	0.747

* : significant at 5 % level, ** : significant at 1 % level, [ ] : Normarized partial regression coefficient



(a) prediction of required drying time beforehand



(b) modification of drying conditions before drying

Fig. 6 Flow cahrt

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