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NEURAL NETWORK BASED SAFE PROCESS TIME PREDICTOR FOR SINGLE SIDED PAN FRYING OF BEEF PATTIES

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Introduction

Hamburger (meat patty) is one of the most popular foods in North America and elsewhere. Eating of undercooked ground beef may result in a type of food poisoning that is commonly called hamburger disease. Hamburger disease is caused by *E. coli* O157:H7, which lives in the intestines of cattles, and can be transferred to the outer surface of carcasses when cattles are slaughtered. The Food and Drug Administration and U.S. Department of Agriculture have recommended a minimum target cooking temperature of 68.3ºC with 16 s holding time for foodservice operations to enhance food safety (USDA-FSIS 1993; FDA 1999). However, it is difficult to implement these standards in a restaurant or at home due to the complexities and difficulties in measuring the internal temperature, and the non-homogenous composition of the patties. Consequently, patties are usually overcooked resulting in poor textural quality. Therefore, to ensure reliable quality and safety of cooked patties, an accurate prediction of the temperature variations within the patties is necessary. Pan-frying, a very popular cooking method, imparts an aromatic, savoury flavor to the patties (Gisslen, 1999). Neural network (NN) is an information processing system, which learns from input/output data to determine the relationships between input/output data, and is used in pattern recognition, classification, etc. In recent years, NN has attracted researchers in many disciplines of science and engineering, since it is capable of correlating large and complex data sets.

Objectives

The objective of this research is to develop NN based prediction of safe cooking time for single-sided pan-frying of frozen and unfrozen beef patties.

Methodology

Heat and Mass (moisture and fat) Transfer Model Development

Moisture and fat transfers were assumed to be due to the capillary flow of water and fat due to shrinkage of the patty and pressure increase at increased temperature. The heat transfer was modeled using Fourier's laws, and energy balances. The models were solved with finite difference approach. Single-sided pan-frying involves patty's flipping time which can be odd and even. The equations of boundary conditions and each node are essentially the same except that there is a reversal of nodes after flipping. The predicted temperature at each node in the patty was used to calculate the destruction rate of a microorganism. The process time was calculated for 12 log reductions of *E. coli* O157:H7 (Ou and Mittal 2005a,b).

Experimental Model Validations

Beef patties were from the same batch to ensure similar composition. Patties were pan-fried on a combo health grill. Additionally on/off proportional controller and solid state relay were used to control the frying temperature of 160°C. During the cooking, the patty was flipped 3 times. The flippings were at an interval of 120 s. Moisture and fat contents during cooking were determined at different cooking times. The temperature histories at the geometric centre, top and bottom layers of the selected patties were also measured using thermocouples with diameter of 0.25 mm, and recorded every 30 s.

The model input parameters include physical and thermal properties of hamburger patties, heating conditions, related coefficients for mass transfer, and thermal resistance of microorganisms. The simulation program was written in MATLAB language and executed on a PC computer. For unfrozen and frozen patties, the root mean squared errors (RMSE) were as: for average moisture and fat contents – 0.10 to 0.17 db and 0.064 to 0.078 db respectively; and central temperatures – 2.3 to 3.0^{o}C. These models predicted various parameters satisfactorily.

Network Training and Testing

By taking pan temperature: 140°C, 160°C and 180°C, product thickness: 8.5, 9.5, 10.5, 11.5 and 12.5 mm, and flipping interval: 1, 1.5, 2, 2.5, and 3 min, 75 datasets were obtained using validated process models. By repeating for unfrozen and frozen patty conditions, total datasets obtained were 150. A NN with 4 input elements (pan temperature, product thickness, flipping interval and patty condition) and 1 output element was build for process time prediction (Fig. 1). Unfrozen patty condition as 0 and frozen condition as 1 were denoted. Taking 22 datasets for testing and 22 datasets for production, remaining 106 datasets were used to train the NN. After every data set training, NN weights were adjusted. Testing datasets were fed to test trained NN after training for 150 epochs. Testing errors were recorded. In the beginning of training, testing error decreased with training process. Training was continued until testing error did not decrease. If testing error was greater than the minimum testing error, then testing was continued until 200 000 epoch training was reached. After training, 22 production sets were used to verify NN performance.

Results & Discussion

First, different hidden layer arrangements and combinations of learning rate 0.5 and momentum 0.5 were chosen to examine the production results. In 22 production sets, percentage of prediction with relative error < 5% was 86.4% using 10 hidden elements NN. Then prediction errors for different learning rate and momentum values using 10 hidden elements were calculated. The maximum percentage of prediction with relative error <5% was 90.9%, using learning rate of 0.7 and momentum of 0.7. Mean absolute error and mean related error were 17.2 s and 3.2% respectively.

Prediction by 3 layer NN could get appreciated accuracy, but sometimes 4 layer NN will get better result. Therefore, prediction results were obtained with different elements in hidden layers and with different leaning rate and momentum. The best result by 4-4 hidden layer NN with learning rate 0.9 and momentum 0.5 provided mean absolute error and mean related errors of 15.6 s and 2.7% respectively. Percentage of prediction with relative error <5% was 95.5%. Thus, prediction errors have not improved using 4 layer NN compared to 3 layer NN.

Examining all of input and output data, the output range was much bigger. It may affect the prediction accuracy. To reduce output ranges, values of process time were transformed using logarithmic function. Two NNs with ln (t) and $\log_{10}$ t as outputs were developed, respectively. After training NN, power functions (e^x or 10^x) were used to transfer predicted data to original process time, and absolute and related errors were calculated. The optimum results were given by $\log_{10}$ function with 3 layer NN having 10 elements in hidden layer (Tables 1-2). Learning rate was 0.5 and momentum was 0.7. Mean absolute error and mean relative error were 12.70 and 2.27% respectively. Percentage of prediction with relative error <5% was 95.4%, Fig. 2 shows the relationship between original process time and predicted time using trained NN.

Conclusions

A simple 3 layer architecture of a neural network was able to predict the safe cooking time for single sided pan frying of beef patties with reasonable accuracy. A neural network is simple to use as compared to simulation process models. The NN with 4 input elements (pan temperature (140 to 180^{o}C), patty thickness (8.5 to 12.5 mm), flipping interval (1 to 3 min) and patty condition (0 for frozen and 1 for unfrozen)) and 1 output element was built for safe process time predictions. The optimum results were obtained when output was transformed by $\log_{10}$ function with 3 layer NN and 10 elements in the hidden layer. Learning rate was 0.5 and momentum was 0.7. The mean absolute error and mean relative error were 12.7 s and 2.3% respectively. The percentage of prediction with relative error less than 5% was 95.4%.

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Tables and Figures

Table 1. Effect of transferred process time data by $\log_{10}$ function on prediction errors for process time using 3 – layer NN (learning rate 0.5 and momentum 0.5)

Elements in hidden layer→	5	7	10	12	14
Mean absolute error, s	18.9	17.6	17.1	14.8	17.7
s.d., s	13.3	12.6	11.6	10.9	12.6
Mean related error, %	3.5	3.2	3.2	2.9	3.4
s.d., %	1.6	1.2	1.8	1.9	2.2
% datasets within 5% relative error	81.8	77.3	86.4	90.9	72.7

Table 2. Effect of learning rate and momentum using $\log_{10}$ function on prediction errors of process time using 3 – layer NN (10 elements in hidden layer)

Leaning rate and momentum→	0.5, 0.5	0.5, 0.7	0.5, 0.9	0.7, 0.5	0.7, 0.7	0.7, 0.9	0.9, 0.5	0.9, 0.7	0.9, 0.9
Mean absolute error, s	14.8	12.7	12.9	18.3	13.7	12.7	12.8	13.6	17.4
s.d., s	10.9	12.5	13.7	13.0	11.4	13.9	10.9	11.1	14.3
Mean related error, %	2.9	2.3	2.3	3.3	2.5	2.3	2.4	2.5	3.1
s.d., %	1.9	1.9	2.0	1.9	1.9	2.1	2.0	1.9	2.0
% datasets within 5% relative error	90.9	95.4	90.9	81.8	95.4	90.9	90.9	86.4	77.3

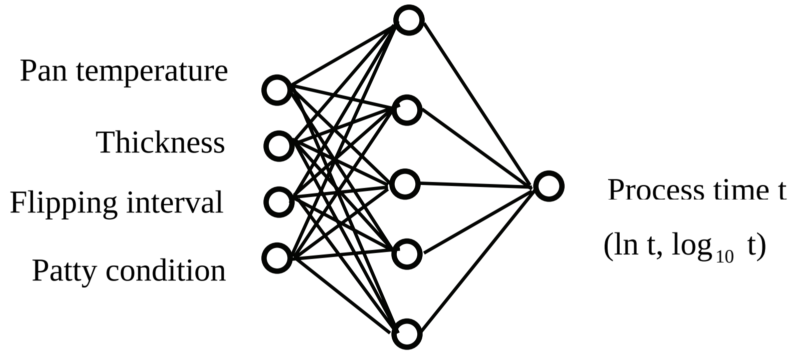

Fig 1. Neural network architecture for predicting safe process time for single sided pan frying of beef patties

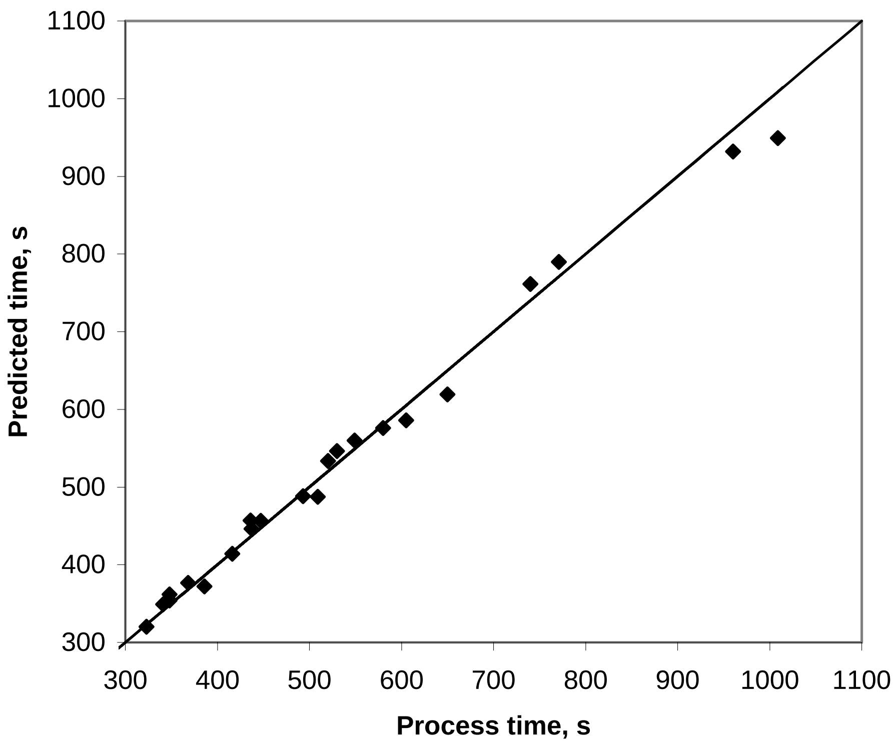

Fig. 2. Process time prediction with 3 layer NN using $\log_{10}$ function transferred process time data (10 elements in hidden layer with learning rate 0.5 and momentum 0.7)