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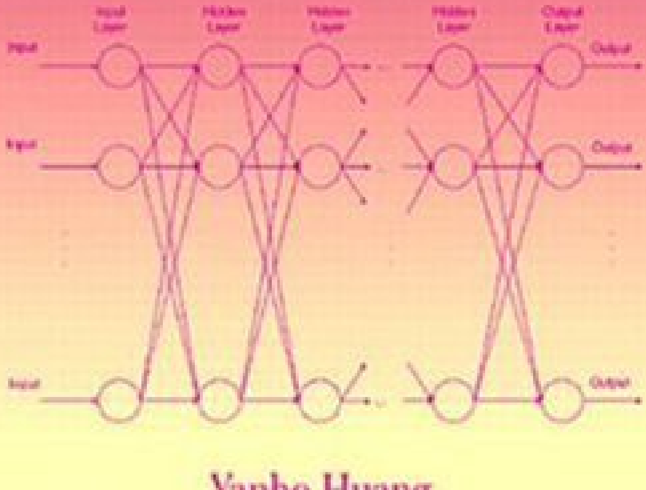
AUTOMATION for FOOD ENGINEERING

Food Quality Quantization and Process Control



Yanbo Huang
A. Dale Whittaker
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Dedication

To Meixi, Tian, and Mamie, and my father, mother, and sister

Yanbo Huang

To my family

A. Dale Whittaker

I would like to dedicate this to my parents who believed in the power of education and to my wife, Sally, and children, Kathryn, Charlotte, and David, who do not always understand what I do or why I do it, but support me anyway

Ronald E. Lacey

Preface

Food quality quantization and process control are two important fields in the automation of food engineering. Food quality quantization is a key technique in automating food quality evaluation. Food quality process control is the focus in food production lines. In the past 10 years, electronics and computer technologies have significantly pushed forward the progress of automation in the food industry. Research, development, and applications of computerized food quality evaluation and process control have been accomplished time after time. This is changing the traditional food industry. The growth of applications of electronics and computer technologies to automation for food engineering in the food industry will produce more nutritious, better quality, and safer items for consumers.

The book describes the concepts, methods, and theories of data acquisition, data analysis, modeling, classification and prediction, and control as they pertain to food quality quantization and process control. The book emphasizes the applications of advanced methods, such as wavelet analysis and artificial neural networks, to automated food quality evaluation and process control and introduces novel system prototypes such as machine vision, elastography, and the electronic nose for food quality measurement, analysis, and prediction. This book also provides examples to explain real-world applications.

Although we expect readers to have a certain level of mathematical background, we have simplified this requirement as much as possible to limit the difficulties for all readers from undergraduate students, researchers, and engineers to management personnel. We hope that the readers will benefit from this work.

Outline of the Book

Six chapters follow the Introduction.

Chapter 2 concerns data acquisition (DAQ) from the measurement of food samples. In Chapter 2, the issues of sampling are discussed with examples of sampling for beef grading, food odor measurement, and meat quality evaluation. Then, the general concepts and systems structure are introduced. The examples of ultrasonic A-mode signal acquisition for beef grading, electronic nose data acquisition for food odor measurement, and snack food frying data acquisition for process quality control are presented. Imaging systems, as they are applied more and more in the area of food quality characterization, are discussed in a separate section. Generic machine vision systems and medical imaging systems are described. Image acquisition for snack food quality evaluation, ultrasonic B-mode imaging for beef grading, and elastographic imaging for meat quality evaluation are presented as examples.

Chapter 3 is about processing and analysis of acquired data. In this chapter, the methods of data preprocessing, such as data scaling, Fourier transform, and wavelet transform are presented first. Then, the methods of static and dynamic data analysis are described. Examples of ultrasonic A-mode signal analysis for beef grading, electronic nose data analysis for food odor measurement, and dynamic data analysis of snack food frying process are presented. Image processing, including image preprocessing, image segmentation, and image feature extraction, is discussed separately. The methods of image morphological and textural feature extraction (such as Haralick's statistical and wavelet decomposition) are described. Examples of segmentation of elastograms for the detection of hard objects in packaged beef rations, morphological and Haralick's statistical textural feature extraction from images of snack food samples, Haralick's statistical textural and gray-level image intensity feature extraction from ultrasonic B-mode images for beef grading, and Haralick's statistical and wavelet textural feature extraction from meat elastograms are presented.

Chapter 4 concerns modeling for food quality quantization and process control. Model strategies, both theoretical and empirical, are discussed first in this chapter. The idea of an input–output model based on system identification is introduced. The methods of linear statistical modeling and ANN (artificial neural network) -based nonlinear modeling are described. In dynamic process modeling, the models of ARX (autoregressive with exogenous input) and NARX (nonlinear autoregressive with exogenous input) are emphasized. In statistical modeling, examples of modeling based on ultrasonic A-mode signals for beef grading, meat attribute prediction modeling based on Haralick's statistical textural features extracted from ultrasonic elastograms, and snack food frying process ARX modeling are presented. In ANN modeling, the examples of modeling for beef grading, modeling for food odor pattern recognition with electronic nose, meat attribute prediction modeling, and snack food frying process NARX modeling are presented.

Chapter 5 discusses classification and prediction of food quality. In this chapter, the methods of classification and prediction for food quality quantization are introduced first. Examples of beef sample classification for grading based on statistical and ANN modeling, electronic nose data classification for food odor pattern recognition, and meat attribute prediction based on statistical and ANN modeling are presented. For food quality process control, the methods of one-step-ahead and multiple-step-ahead predictions of linear and nonlinear dynamic models, ARX and NARX, are described. The examples of one-step-ahead and multiple-step-ahead predictions for the snack food frying process are presented.

Chapter 6 concentrates on food quality process control. In this chapter, the strategies of IMC (internal model control) and PDC (predictive control) are introduced. Based on the linear IMC and PDC, the ANN-based nonlinear IMC and PDC, that is, NNIMC (neural network-based internal model control) and NNPDC (neural network-based predictive control), are extended and described. The algorithms for controller design also are described. The methods of controller tuning are discussed. The examples of NNIMC and neuro-fuzzy PDC for the snack food frying process are presented.

Chapter 7 concludes the work. This chapter is concerned with systems integration for food quality quantization and process control. In this chapter, based on the discussion and description from the previous chapters concerning system components for food quality quantization and process control, the principles, methods, and tools of systems integration for food quality quantization and process control are presented and discussed. Then, the techniques of systems development, especially software development, are discussed for food quality quantization and process control.

Yanbo Huang

A. Dale Whittaker

Ronald E. Lacey
College Station, Texas
May 2001

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Contents

chapter one

Introduction

1.1 Food quality: a primary concern of the food industry

The quality of foods is of primary importance to the food industry and to consumers. Consumers want food products that are good, nutritious, and safe. High quality food products can boost the profitability of the food supply chain from farming, processing, and production to sales, thus, strengthening the entire enterprise. However, any failure of a food product may result in a consumer returning the product to the seller, writing a complaint letter to the manufacturer, or even filing a lawsuit against the food company. The failure may be the under fill of a package, off-flavor, odor, staleness, discoloration, defective packaging, expired shelf life, incurred illness, and so on. For the sake of meeting consumers' needs, the food industry has the obligation to produce food items that are uniform in quality, nutritious, and safe. A food company needs to have adequate quality assurance systems and active quality control systems to keep its products competitive in the market.

1.2 Automated evaluation of food quality

Evaluation is the key to ensuring the quality of food products. Often, evaluation detects component adequacy and documents mechanical, chemical, and microbiological changes over the shelf life of food items. Both qualitative and quantitative evaluation can provide the basis for determining if a food product meets target specifications. This quality information also provides feedback for adjustments to processes and products needed to achieve target quality

There are two methods for evaluation of food quality. One is subjective, based on the judgment of human evaluators. The other is objective, based on observations excluding human evaluators' opinions.

Subjective methods require the human evaluators to give their opinions regarding the qualitative and quantitative values of the characteristics of the food items under study. These methods usually involve sensed perceptions of texture, flavor, odor, color, or touch. However, even though the evaluators are highly trained, their opinions may vary because of the individual variability involved. Sensory panels are a traditional way to evaluate food quality. Although highly trained human evaluators are intelligent and able to perceive deviation from food quality standards, their judgments may not be consistent because of fatigue or other unavoidable mental and physical stresses.

The output of food quality evaluation is the primary basis for establishing the economic value of the food products for farmers, manufacturers, and consumers, and it can be useful for quality control of food products. Because traditional manual quality control is time-consuming, can be error prone, and cannot be conducted in real time, it has been highly desirable for the food industry to develop objective methods of quality evaluation for different food products in a consistent and cost-effective manner. The objective methods of food quality evaluation are based on scientific tests rather than the perceptions of human evaluators. They can be divided into two groups:

1. Physical measurement methods are concerned with such attributes of food product quality as size, texture, color, consistency, and imperfections. There are several sensors adapted for the physical evaluation of food product quality.
2. Chemical measurement methods test for enzyme, moisture, fiber, pH, and acidity. In many cases, these tests can be used to determine nutritive values and quality levels.

The development of computer and electronics technologies provides strong support to fast, consistent signal measurement, data collection, and information analysis. The greatest advantage of using computer technology is that once the food quality evaluation systems are set up and implemented, the system will perceive deviation from food quality standards in a consistent way and not experience the mental and physical problems of human evaluators. Another major benefit of using computer technology in food quality systems is that it is possible to integrate a large number of components to automate the processes of food quality evaluation. This automation can result in objective, fast, consistent food quality evaluation systems, a significant advancement for food engineering and industry.

This book will focus on the techniques for objective and automated food quality evaluation, especially nonintrusive/noninvasive food quality evaluation.

1.3 Food quality quantization and process control

Food quality quantization allows information to be represented numerically in a mathematical expression. The process of the representation is often automated. In evaluation, indicators of food quality such as analytical, on-line sensor, and mechanical measurements of food samples need to be quantized in use for assessing quality. Basically, food quality quantization is the mimic of human intelligence with machine intelligence in food quality evaluation. The machine intelligence is used to "view," "touch," and/or "taste" the food samples and, then, to differentiate them in a way that is often guided by results from a human sensory panel. The performance of the quantization is usually measured by a comparison of the quantitative data with sensory, classification assignment, or mechanical and chemical attribute measurements.

In general, the procedure of food quality quantization is as follows:

1. Sampling—the first step in food quality quantization involves collecting food samples according to a designed sampling procedure. The procedure is designed to produce enough data samples under different experimental conditions to be able to draw a conclusion with a certain statistical significance. When the samples are extracted, they need to be further processed, stored, and delivered onto the experimental board for measurement.
2. Data acquisition—sensors and transducers measure the collected food samples. The electrical signals indicate physical properties of the food products. The signal data are conditioned, converted, and stored for later processing and analysis.
3. Data processing and analysis—the data are processed, usually scaled or normalized, to produce a consistent magnitude between variables. The relationships between variables are tested and correlations between variables are determined. This step helps make decisions based on modeling strategy.
4. Modeling—mathematical models are statistically built between the (input) variables of the physical property measurements of food samples and the (output) variables of human sensory quantities, classification assignments, or mechanical and chemical measurements of the samples. The models determine quantitative relationships between the input and output variables.
5. Classification or prediction—based on the models, the food samples can be classified or predicted for their sensory, mechanical, and chemical attributes. The accuracy of the classification or prediction is calculated.

In this way the performance of the quantization can be evaluated based on the accuracy of the classification or prediction. If the performance is satisfactory, the food quality quantization scheme can be used in practical food quality evaluation; otherwise, it becomes necessary to reassess the modeling, data processing and analysis, data acquisition, or even sampling procedures to locate the spot(s) to refine the scheme. Figure 1.1 shows a diagram of the procedure for food quality quantization.

Food quality process control occurs when the difference between measurements of actual food quality and specifications of food quality is used to adjust the variables that can be manipulated to change product quality. The variables that indicate food quality may be quantities like color and

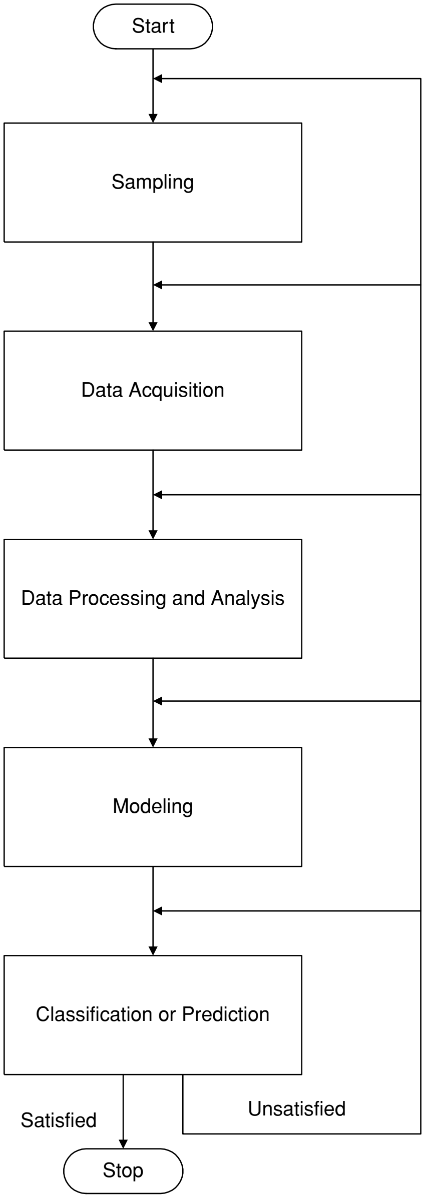

Figure 1.1 Diagram of the procedure for food quality quantization.

moisture content. The adjusted variables are quantities such as inlet temperature and material cooling conveyor speed in a continuous snack food frying process. These adjustments are made based on the computation of certain algorithms in an attempt to eliminate the deviation of observed quality from the target specifications for the product. In general, the adjustments can be done either when the problems occur or on a regular basis. The former is quality control (Besterfield, 1990) while the latter is process control, the topic of this book. Food quality process control applies methods and tools of process control to adjust the operating conditions in terms of the quality specifications of food processes for the consistency of food product quality.

In general, the procedure of food quality process control is as follows:

1. Sampling—sampling is performed in terms of the requirements of food quality process control. It needs to design experiments which produce enough data samples in different conditions with certain statistical significance. For effective process control, the collected samples need to be able to produce the measured data to cover the designated frequency range to represent the process dynamics sufficiently.
2. Data acquisition—with the prepared samples, the values of the food quality indication variables are measured by sensors and transducers, and the corresponding data for process operating conditions are recorded.
3. Data processing and dynamic analysis—the data are processed, usually scaled or normalized, to produce a consistent magnitude between variables. The dynamic relationships between variables are tested. The autocorrelations and cross correlations between variables are determined. This step helps make the decision about the process modeling strategy.
4. Modeling—linear or nonlinear discrete-time dynamic mathematical models are statistically built between the (input) variables of the levels of actuators in food processes and the (output) variables of food quality indication. The models determine quantitative, dynamic relationships between the input and output variables.
5. Prediction—based on the models, the quantities of food quality indications can be predicted in one-step-ahead or multiple-step-ahead modes. The accuracy of the predictions reflects the capability of the prediction models in control loops.
6. Controller design—the built process models are used to design the controllers based on certain algorithms. The controllers are tuned in order to perform well in the regulation of the process operating conditions to ensure the consistent quality of the final products.

The performance of the process control systems can be evaluated based on the specifications and requirements of the food processes. If the performance is satisfactory, the food quality process control scheme may be implemented in practice; otherwise, it needs to go back to the starting points of controller design, prediction, modeling, data processing and dynamic analysis, data acquisition, or even an experiment design to locate places to refine the scheme. Figure 1.2 shows the diagram of the procedure for food quality process control.