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Automated quality control in the food industry combining artificial intelligence techniques with fractal theory

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Abstract

Traditional Quality Control in the Food Industry consists mainly of microbiological and chemical techniques performed on samples of food extracted from production lines. Traditionally, the goal of the Quality Control department in the Food Industry has been the application of the minimal number of microbiological and chemical techniques to the samples of food, so as to have a decision on the quality of the production as quickly as possible. In this paper we are introducing a new computerized method to perform an automatic evaluation of the quality of the production, based on Artificial Intelligence (AI) techniques and Fractal Theory. The main idea in this paper is that, combining the use of the fractal dimension as a measure of classification of microorganisms and chemicals, and the use of AI to simulate the expert evaluation/decision process of the quality of the production, we obtain a computer program that is able to perform automated quality control in the food industry. We can conclude then, that the use of AI and Fractal Theory increases quality control efficiency (in accuracy and in time) because it eliminates the need of the application of a long sequence of microbiological and chemical techniques.

1 Introduction

Traditional Quality Control in the Food Industry consists of a long sequence of microbiological and chemical lab techniques that have to be performed on samples of food extracted from production lines [5]. Traditionally, the goal of the Quality Control department has been the application of the minimal number of microbiological and chemical techniques to the samples of food, so as to have a decision on the quality of the production as soon as possible. The goal of the microbiological and chemical techniques is the identification of possible harmful microorganisms and toxic chemicals for the final consumers of the food [6,7]. This is the information that is evaluated at the end, by the human experts in Quality Control, to make the final decision about the quality of the production.

In this paper we describe a new method to perform Automated Quality Control in the Food Industry, using AI techniques [1] and Fractal Theory [4]. We also show in this paper how to implement this new method as a computer program to really achieve the goal of Automated Quality Control in the practice. We use Fractal Theory in our new method to minimize the number of microbiological and chemical techniques that are needed to make the identifications of harmful microorganisms and toxic chemicals. We use a method for the identification of microorganisms based on the use of the fractal dimension, developed by the authors [2], to eliminate the need of applying a long sequence of microbiological techniques to the samples of food. This method of identification uses the fractal dimension as a measure of classification of the microorganisms and can greatly reduce the time needed to identify possible harmful microorganisms for the consumers. The computer program contains a module to perform this fractal identification, which in turn enables automated identification of microorganisms without using microbiological techniques. On the other hand, we use AI techniques to simulate the expert evaluation/decision process to obtain the quality of the production. The process of Quality Evaluation is simulated in the computer program using as input the information about the identifications of microorganisms and chemicals, and then by applying heuristics and statistical calculations to decide on the degree of quality of the production. The computer program contains an "intelligent" module to perform this "expert" simulation, which in turn results in automated evaluation of Production Quality. In conclusion, we can say that combining the use of both AI techniques and Fractal Theory in a computer program we can achieve the desired goal of Automated Quality Control in the Food Industry (AQCFI).

The use of AI and Fractal Theory increases the efficiency (in accuracy and in time) of the quality control, because the computer program has the mathematical algorithms (for the fractal dimension) needed to identify possible harmful microorganisms and toxic chemicals without microbiological or chemical techniques for the identification, and also because the computer program has the knowledge to decide at the end on the final quality of the food production. In this paper the authors have successfully generalized their previous work on this matter [3], by using a Fractal module to perform automated identification of microorganisms and chemicals and by adding an Expert module for evaluation of the quality of the production.

In order to develop the Expert Module of the computer program we needed to perform knowledge extraction from the human experts (in microbiology and in chemistry) in quality control for the food industry. The knowledge acquisition for the Expert Module was done by one of the authors

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while working in the quality control department of a particular fish processing plant in Mexico. The Expert Module consists of a set of rules in PROLOG [8], containing the knowledge of the human experts for the domain of quality control in the Food Industry. Also the knowledge base of the system can be updated with new rules by using the "learning module".

The reasons why we consider that Automated Quality Control is important for this domain of application are the following:

1.- There are not enough experts in quality control for the food industry for all the food manufacturing plants in Mexico.

2.- The domain of quality control for the food industry is a complex one, because of the very different types of microorganisms or toxic chemicals that can be found in food, and also because of the many microbiological or chemical methods that can be used for identification.

3.- There is a need of making more efficient the task of quality control, not only in the time needed to perform the identifications of possible microorganisms or toxic chemicals, but also in the accuracy of the results. The need of increasing this efficiency can be justified with the goals of the Company of reducing times and costs of production, and also preventing harm to the final consumers of the food.

2 Description of the new method for automated quality control

The new method for Automated Quality Control in the Food Industry consists mainly of two parts: one part performs the automated identification of microorganisms and chemicals by using the fractal dimension, and the second part performs an automated evaluation on the quality of the production by using AI techniques and the information obtained in part one. We show in figure 1 how the new method works, beginning with the samples of food extracted from production lines and ending with the final evaluation of the production quality. We describe below in more detail the two main parts of the new method for AQCFI.

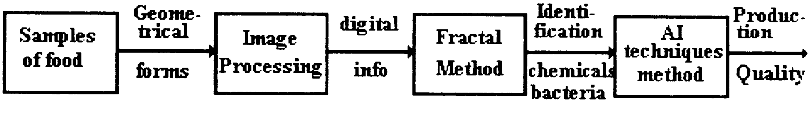

Figure 1.- New Method for Automated Quality Control in the Food Industry

2.1 Description of the method for the identification of microorganisms and chemicals using the fractal dimension

We describe briefly in this section a new method for the identification of microorganisms for the food industry, developed by the authors [2], that is

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based on the use of the fractal dimension [4]. This method uses the fractal dimension to make a unique classification of the different types of microorganisms, because it is a known experimental fact that the colonies of different types of bacteria have different geometrical forms [5]. The problem is then of finding a one to one map between the different types of bacteria and their corresponding fractal dimension, in this way obtaining a unique method of identification of microorganisms for the food industry. The first step in obtaining this map is to find experimentally (in the microbiological lab) the different geometrical forms for the bacteria. The second step is to calculate the corresponding fractal dimensions for the different types of bacteria. This fractal dimension can be calculated for a selected type of bacteria with several samples, to obtain as a result a statistical estimation of the dimension and the corresponding error of the estimation.

In order to make an efficient use of this map between the different types of bacteria and their corresponding estimated dimensions, we need to implement it as a module in the computer program. The implementation of the map as a module in the program will be described later in section 3.2. A similar method for the identification of chemicals can be developed using the fractal dimension.

2.2 Description of the method to perform automated evaluation of production quality

We describe briefly in this section the method to perform the evaluation of production quality using AI techniques. This method simulates the expert evaluation/decision process involved in obtaining the degree of quality of the production. This method uses as input the information obtained by the "Fractal Method", i.e. the identification of microorganisms and chemicals, and then applies heuristics and statistical calculations to decide on the quality of the production. This method uses expert knowledge to decide if a microorganism can be harmful to the consumer or if a chemical can be toxic to the consumer. Also, the method uses expert knowledge to decide on the degree of quality of the production. Both kinds of expert knowledge can be implemented in PROLOG as a set of rules (knowledge base) for the computer program. The implementation of the method for Automated Evaluation of production Quality is described in section 3.3. The choice of PROLOG is because of its symbolic manipulation features and also because it is a good language for developing prototypes.

3 Description of the computer system and implementation strategies

We describe below the general architecture of the computer system. The modules of the system are: the Expert Module, the Fractal Module, the Interface, the Inference Engine and the Learning Module. The description of the Inference Engine is based mainly on the Prolog Programming Language [1] and

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is not given in this paper. The description of the Expert Module, the Fractal Module and the Learning Module is given below, because it is very interesting from the point of view of the application to manufacturing in the food industry. We also give a description of the implementation strategies used in developing the computer system.

3.1 Architecture of the computer system

In figure 2 we describe the general architecture of the system.

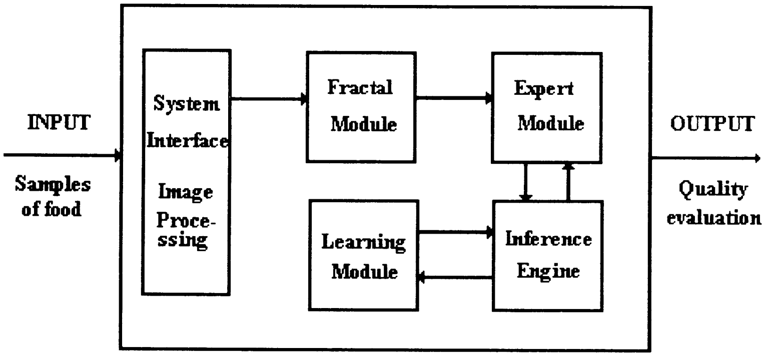

Figure 2.- General Architecture of the System

3.2 Description of the fractal module

The Fractal Module consists of a computer program that is an implementation of the method for the identification of microorganisms and chemicals using the fractal Dimension, described in section 2.1 of this paper. This computer program uses the geometrical forms of the colonies of microorganisms, obtained by the Interface of the system from the samples of food, to estimate the fractal dimension (box dimension) using a known algorithm [4], and then compares this value with the data base of known fractal dimensions and their corresponding identifications (this is the one to one map mentioned in section 2.1), to arrive to the conclusion of which microorganisms are present in the samples of food. This computer program also uses the geometrical forms of the spectrums of unknown chemical compounds in the samples of food, to estimate their fractal dimensions and then compares this value with the data base of known Chemical Identifications, to arrive to the conclusion of which chemical compounds are present in the samples.

3.3 Description of the expert module

The Expert Module of the computer System is an implementation of the method to perform automated evaluation of production quality (described in section 2.2 of this paper). The Expert Module uses the information given by the Fractal Module to obtain the quality of the production, i.e., the Expert Module uses the identifications of microorganisms and chemicals found in the samples of food to

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decide if the quality of the production meets the requirements of acceptance. The knowledge base of the Expert Module consists of a set of rules containing the knowledge of the human experts for the domain of quality control in the Food Industry. The knowledge base consists of two parts: one part contains the knowledge to decide if a microorganism is harmful to the consumer or if a chemical is toxic to the consumer, the second part contains the knowledge to decide on the degree of quality of the production.

To give an idea of the way the knowledge base is structured, we show some sample rules of the part of knowledge base that decides if a microorganism is harmful to the consumer.

Rule 1:
IF Microbiological_Identification = salmonella_typhi
THEN Microbiological_Conclusion = dangerous_species_can_cause_infection

Rule 2:
IF Microbiological_Identification = staphylococcus_aureus
THEN Microbiological_Conclusion = dangerous_species_can_cause_intoxication

Rule 3:
IF Microbiological_Identification = escherichia_coli
THEN Microbiological_Conclusion = slightly_dangerous_species

Rule 4:
IF Microbiological_Identification = pseudomonas_aureoginosa
THEN Microbiological_Conclusion = not_dangerous_species

Rule 5:
IF Microbiological_Identification = nil
THEN Microbiological_Conclusion = no_species_at_all

Of course, the above rules are only for deciding if certain types of microorganisms are harmful to the consumer, but there are many more rules in the actual knowledge base for the other types of microorganisms that the computer system can handle at the moment. Also the knowledge base contains similar rules for deciding is a chemical can be toxic to the consumers.

The knowledge base also has rules to perform a final evaluation of the quality of the manufacturing process for the food production. This rules decide on the quality of the production, using as information the microorganisms and chemicals found in the samples of food.

We show below some sample rules for "quality evaluation".

Rule 6:
IF Microbiological_Conclusion = dangerous_species_can_cause_intoxication
AND Chemical_Conclusion = toxic_chemicals
THEN Quality = bad_reject_production

Rule 7:
IF Microbiological_Conclusion = dangerous_species_can_cause_infection
AND Chemical_Conclusion = toxic_chemicals
THEN Quality = bad_reject_production

Rule 8:
IF Microbiological_Conclusion = slightly_dangerous_species
AND Chemical_Conclusion = low_percentage_of_slightly_toxic_chemicals
THEN Quality = regular_more_tests_to_decide

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Rule 9:

IF	Microbiological_Conclusion = not_dangerous_species
AND	Chemical_Conclusion = not_toxic_chemicals
THEN	Quality = good_accept_production

Rule 10:

IF	Microbiological_Conclusion = no_species_at_all
AND	Chemical_Conclusion = no_chemicals_at_all
THEN	Quality = excellent_accept_production

Of course, the above rules are only for deciding on the quality of the production for certain specific cases, but there more rules in the actual knowledge base for other cases that the computer system can handle at the moment.

3.4 Description of the learning module

The goal of having a Learning Module for our system, is to have a computer program that can be updated with new rules for deciding if a microorganism is harmful or if a chemical is toxic for the consumers, and also with new rules for deciding on the quality of the production. Of course, the job of updating the system can only be done by the human experts or by the knowledge engineers, and not by other users.

When the learning module is activated the system creates new rules for the knowledge base using the data given by the human experts. The method for learning rules that the computer system uses is known as "learning by example" and is described briefly by Bratko [1].

3.5 Description of the implementation strategies

We describe in this section the implementation strategies used in developing the computer system. This description is divided according to the modules of the system. First of all, for our implementation of the "System Interface" we used a particular Laser Scan Microscope (LSM). The LSM receives as input the samples of food (in prepared plates) and applies imaging processing techniques to give us the digitized information about the geometrical forms for the colonies of bacteria. For our goal of obtaining automated identification the LSM was the better option, because it solved for us the problem of designing and developing the interface. Second of all, the implementation of the "Fractal Module" consists of two parts: implementing a computer program for calculating the fractal dimension and implementing a program for the identification of microorganisms and chemicals. The program for calculating the fractal dimension was developed using the C programming Language as an implementation of the box dimension algorithm. The choice of C was because of its efficiency for extensive numerical calculations and this is what is needed for the box dimension algorithm. On the other hand, the program for identification was developed in the PROLOG programming language, because the process of identification requires searching a data base of known classifications of microorganisms and chemicals. The choice of PROLOG is because of its efficiency for implementing a data base. The information in the data base was obtained by prior extensive microbiological and chemical experimental work done by the authors [2] using the LSM and the fractal method.

The "Expert Module" consists of a Knowledge Base(KB) for performing automated evaluation of production quality. This KB consists of a set of rules for the simulation of the production quality decision process. We decided to implement this KB using the PROLOG programming language because of its symbolic manipulation features.

The "Learning Module" was developed also in the PROLOG programming language. This module is an implementation of the induction learning algorithm for this domain. This computer learning program was also used in the early stages of the development to build the initial KB for the system, using as input the information obtained from the knowledge acquisition phase and obtaining in this way the set of rules for the KB of the system.

4 Use and validation of the system

The computer system for automated quality control in the food industry has been tested in a fish processing plant in Mexico, for several months with encouraging results. With the computer program, the people in the quality control department were able to know in less time the quality of the production. We can say that the computer program provided a more efficient method (required less time and more accurate than conventional methods) to evaluate the degree of quality of the production. The importance of making more efficient this quality control can be justified at least in two ways:

1.- Preventing harm to the final consumer of the food in the way of intoxication or infection, with obvious loses for the people and for the company.

2.- Reducing times for quality control obviously results in decreasing the costs of producing the final food product.

After using the computer system as a tool in the quality control department, the users suggested several possible improvements to make it more easy to use and to extend the applications of the computer program. Several of this possible improvements suggested by them and also some improvements that we think can be useful can be find in the next section.

In figure 3 we show the initial screen of the computer system in use. If a user selects the "start-up" option in the menu, then the computer system will automatically perform the quality control. Of course this is only done if the user has the food samples on line with the LSM. If a user selects another option then the system will do the corresponding task.

In figure 4 we show the final output of the system for a set of samples of food that contain the bacteria salmonella typhi, which is considered very harmful for the consumers and this fact is in turn very critical for the final evaluation of production quality. The final screen consists of four windows: final evaluation of quality, microbiological evaluation, chemical evaluation and

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explanation. In each window the user will find the corresponding information about the automated quality control performed on the samples of food. In the explanation window the user can ask for further information on the quality, microbiological or chemical evaluation given in the other windows.

AUTOMATED QUALITY CONTROL IN THE FOOD INDUSTRY
DEVELOPED BY O. CASTILLO AND P. MELIN

This computer system uses the Laser Scan Microscope(LSM) for image processing and the box dimension algorithm for fractal dimension calculations and the knowledge base developed by O. Castillo and P. Melin for performing Quality Control in the Food Industry.

Please select one of the following options:

(a) start-up the system (food samples on-line)
(b) check-up the system (for testing)
(c) explanation of how the system works
(d) exit

?-a.

Figure 3.- Initial screen of the computer system.

AUTOMATED QUALITY CONTROL IN THE FOOD INDUSTRY
DEVELOPED BY O. CASTILLO AND P. MELIN

FINAL EVALUATION OF QUALITY: The quality of the production is "bad_reject_production" because harmful bacteria were found

MICRO-EVALUATION:
The following bacteria were found
-Salmonella thypi in 90% of the samples
-Pseudomona aureoginosa in 10% of the samples

CHEMICAL EVALUATION:
no_chemicals_at_all

EXPLANATION:
press F1 - F3 for explanation

F1 Micro F2 Chemical F3 Quality F4 Printout F5 Restart F6 Exit

Figure 4.- Final output of the computer system.

5 Conclusions

We have developed a computer system for automated quality control of the manufacturing process for the food industry. The computer system is an implementation of a new method developed by the authors for automated quality control (described in section 2), based on the use of AI techniques and

Fractal Theory. The system can be used by the people in the quality control department, to know if the food contains harmful microorganisms or toxic chemicals to the consumer. The system also has the ability to "learn" new rules for decision of quality and identification, and as a result of this can be updated at any moment by the human experts.

In a prior prototype system developed by the authors [3] the use of AI was only for the selection of the microbiological techniques needed to identify the microorganisms present in the samples of food and this is only part of the problem in quality control. In the computer system presented now in this paper, the Fractal Module eliminates the need of using microbiological techniques for the identification of microorganisms. Also, the Fractal Module identifies chemicals present in the samples of food. In the system described in this paper, the use of AI techniques is for the simulation of the decision process of finding if a microorganism can be harmful or a chemical can be toxic for the consumers. Also, the system uses AI techniques for the simulation of the evaluation process of the quality of the production using the information given by the Fractal Module. We can conclude then that in this paper the authors have successfully generalized their previous work on this matter, with a computer system that can perform automated quality control in the Food Industry (considering Microbiological and Chemical Analysis). Also, we can conclude that the combination of AI and Fractal Theory is giving us a better method for Quality Control (more efficient in time and in accuracy).

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