

Automated mathematical modelling and simulation for bacteria growth control in food engineering

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Abstract

We describe in this paper a computer program for Automated Mathematical Modelling and Simulation (AMMS) for Bacteria growth control in the food industry using Artificial Intelligence (AI) techniques. This computer program is an implementation of a new method for AMMS using Expert Systems technology and Fractal Theory developed by the authors. We show in this paper mathematical models expressed as differential equations, for the simulation of bacteria growth for several types of food. The goal of constructing this models is to capture the dynamics of bacteria population in food, so as to have a way of controlling this dynamics for Industrial purposes. Controlling the growth of bacteria is very important in industrial microbiology in obtaining the food products with the desired chemical and microbiological properties. The goal of controlling the growth of bacteria population can be achieved, by computer simulations and application of the theory of dynamical systems. We also use the fractal dimension as a tool for the identification of bacteria by measuring the geometrical complexity of the colonies. This method of identification is based on the experimental fact that different types of bacteria have colonies of different geometrical form and complexity.

1 Introduction

Many products of considerable economic value for us humans are the result of the metabolic functions of microorganisms. From the industrial point of view, the substrate can be considered as the raw material and the microorganisms as the chemical "micro-industry" that transforms this material into new products. The general reaction is shown in Figure 1.

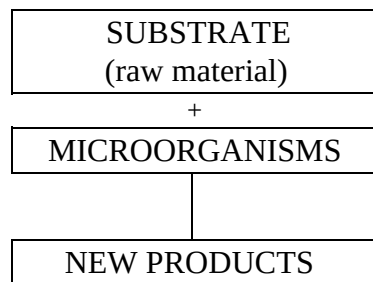


Figure 1 General Reaction for Food Production using Bacteria

Some of the requirements for this industrial microbiological process are:

- 1.- The microorganism to be used has to be capable of producing large quantities of the product. The microorganism has a high growth rate and is not harmful to the consumers.
- 2.- The substrate has to be available in large quantities and has to be relatively cheap. In some cases the substrate is a subproduct of another industrial process.

The product resulting from industrial microbiology can be classified in the following groups: 1) Alcoholic Beverages, 2) Chemical Pharmaceutical Products, 3) Food Supplements and 4) Other Chemical Products. The microorganisms used for developing this products can be Fungi, Viruses or Bacteria.

We describe in this paper a new method to perform AMMS for the problem of Bacteria Growth Control in Food Engineering (BGCFE) using Expert Systems technology and Fractal Theory. The idea of using Expert Systems (ES) technology and Fractal Theory (FT) for this problem can be justified if we consider that traditional methods for BGCFE require a lot of human expert and computer time for numerical simulations. Traditional methods for BGCFE involve a process of model selection for given specific problem and then a process of numerical exploration of the dynamical behaviors of the model. This traditional methods require a team of human experts to decide which mathematical model is considered the "best" for the problem and then a process of extensive computer simulations of the "best" model, to obtain the optimum

control for the food manufacturing process. Also, we use non-linear (dynamical) models instead of traditional statistical models, because it is a well known fact from Dynamical Systems Theory, see Devaney⁹, that non-linear models can exhibit a rich diversity of dynamical behaviors, ranging from very simple periodic solutions to very complicated "chaotic" behavior.

We describe a prototype implementation of our new method for AMMS as a computer program written in the PROLOG programming language². This computer program can be considered an intelligent system for the domain of BGCFE because it uses AI techniques to obtain the "best" mathematical model for a given food engineering problem, and then uses AI techniques to automatically perform computer simulations of the "best" model to obtain the optimum control of the food manufacturing process. The use of AI techniques is to achieve the goal of AMMS of food engineering problems by simulating (in the computer) how human experts in this domain obtain the "best" model for a given problem and then how the experts proceed in obtaining the "best" simulations for this model. Given a food engineering time series, the computer program develops mathematical models based on the geometry of the data. For this, the computer program uses the concept of the fractal dimension, see Mandelbrot¹⁰, to classify the components of the time series over a set of qualitative values, then the program uses this information to decide (using a rule base) which dynamical models are the most appropriate for the data, and finally the program decides which model is the "best" one for the problem using heuristics and statistical calculations. The authors have developed before several prototype intelligent systems for mathematical modelling of economical and financial problems, see Castillo & Melin^{4,6}, and several intelligent systems for the simulation of dynamical systems, see Castillo & Melin^{3,7}, however this computer programs didn't consider using the fractal dimension as a measure of classification and also they were only developed with the goal of having intelligent decision support tools. In this paper, we are now describing how to automate the process of modelling and simulation for BGCFE and also we are considering for the first time the integration of the methods for modelling and simulation.

2 The problem of food production using bacteria

In this section we consider briefly the problem of food production using bacteria for industrial purposes. Many different food products are the result of bacteria population and the best example of this is the set of dairy (milk) products. We show in Table 1 some dairy food products and the corresponding bacteria usually used in the manufacturing process, see Pelczar & Reid¹¹.

We will consider the problem of food production for the case of yogurt. In this case the use of *Streptococcus thermophilus* and *Lactobacillus bulgaricus* is to produce Lactic Acid which is the critical chemical compound necessary for obtaining this product with the exact properties. The right use of this two types

of bacteria in this case, i.e., right temperature and time, results in more quantity of yogurt and of better quality.

Another case is the one of cheese production. Different kinds of cheese require different types of Bacteria and different production processes. However, we can say that in general the goal is to produce the maximum quantity of cheese possible and this requires controlling the growth of Bacteria present and also controlling in the best way possible the conditions of production (temperature and time, for example). We can say almost the same thing for the butter and other food products.

We can say then, that from the industrial point of view the goal is to obtain the maximum quantity of the food product with the desired chemical and biological properties. However, this goal from the engineering point of view can be translated to obtaining the "best" control possible for the food generation process, and this involves modelling Bacteria population in the substrate. This problem will be discussed in greater detail in the next section, where a family of mathematical models (of the Lotka-Volterra type) is presented for BGCFE modelling.

Table 1.- Sample food product and the bacteria used in their production

FOOD	BACTERIA
BUTTER	Streptococcus lacticus Leuconostoc citrovorum
CHEESE	Streptococcus lactis Streptococcus cremoris
YOGURT	Streptococcus thermophilus Lactobacillus bulgaricus

3 Mathematical modelling of the problem

The mathematical problem is then of modelling the population of bacteria in the substrate as they produce the chemical compound needed for the corresponding food product. For a specific case this may require testing several models before obtaining the "best" mathematical model for the food process. In this paper we consider the best model the that fits more closely the data for a given problem. After deriving this "best" model, then the problem is of obtaining computer simulations to decide on the "best" control possible for the food generation process. In this paper we consider the best control the one that maximizes food production for a specific case.

For the case of yogurt we need to have a mathematical model for the population of *S. thermophilus* and *L. bulgaricus* and the quantity of Lactic Acid

produced by both bacteria. In this case we require a Lotka-Volterra type model consisting of a system of three simultaneous differential equations, modelling the situation of two bacteria populations and one chemical compound concentration.

For other food products the number of bacteria needed for production may be different than for our example. In this section we show mathematical models for one, two or three bacteria to explain how we can try in model this problem.

We will consider first the case of using only one bacteria for food production. The mathematical model in this case can be of the following form:

$$dN/dt = r(1 - N/K)N - \beta N$$

$$dP/dt = \beta N$$

where: N = population of bacteria, P = quantity of chemical product, r = rate of growth of bacteria, K = limiting capacity of the environment (substrate quantity) and β = biochemical conversion factor.

We will consider now the case of two bacteria used for food production:

$$dN_1/dt = [r_1 - (r_1/K_1)N_1 - (r_1/K_1)\alpha_{12}N_2]N_1 - \beta N_1$$

$$dN_2/dt = [r_2 - (r_2/K_2)N_2 - (r_2/K_2)\alpha_{21}N_1]N_2 - \gamma N_2$$

$$dP/dt = \beta N_1 + \gamma N_2$$

where: N_1 = population of bacteria1, N_2 = population of bacteria2, P = quantity of chemical product, r_1 = rate of growth of bacteria1, r_2 = rate of growth of bacteria2, K_1 = capacity of the environment for bacteria1, K_2 = capacity of the environment for bacteria2, β = biochemical conversion factor from bacteria1 to product, γ = biochemical conversion factor from bacteria2 to product, α_{12} and α_{21} are coefficients.

Another interesting case will be if one considers two "good" bacteria for food production and one "bad" bacteria that is "attacking" the other bacteria:

$$dN_1/dt = [r_1 - (r_1/K_1)N_1 - (r_1/K_1)\alpha_{12}N_2]N_1 - \beta N_1 - \sigma_1 N_1 N_3$$

$$dN_2/dt = [r_2 - (r_2/K_2)N_2 - (r_2/K_2)\alpha_{21}N_1]N_2 - \gamma N_2 - \sigma_2 N_2 N_3$$

$$dN_3/dt = [r_3 - (r_3/K_3)N_3] + \sigma_1 N_1 N_3 + \sigma_2 N_2 N_3$$

$$dP/dt = \beta N_1 + \gamma N_2$$

where: N_3 = population of bacteria3 (bad bacteria), r_3 = rate of growth of bacteria3, K_3 = capacity of the environment for bacteria3 and σ_1 , σ_2 = rate of attack of bacteria3 to the other bacteria.

This last two cases are more interesting from the mathematical point of view, because it is well known fact from Dynamical System theory that a model of three or more coupled non-linear differential equations can exhibit the behavior Known as "chaos". This chaotic behavior has to be avoided for this

kind of problems, because we need to have a stable food production process. Then, part of the problem in this case will be to control the food production process avoiding the chaotic regime of this type of mathematical models.

The problem is then of finding the maximum of the following objective function (for the case of two types of bacteria):

$$\text{Profit} = aP - b_1N_1 - b_2N_2 - C$$

where: P = chemical product quantity, N_1 = bacteria1 population, N_2 = bacteria2 population, C = fixed costs and a , b_1 , b_2 are constants.

With the following constraints:

$$P \leq P_0, N_1 \leq N_{10}, K_1 \leq K_{10}, N_2 \leq N_{20} \text{ and } K_2 \leq K_{20}$$

where P_0 , N_{10} , N_{20} , K_{10} , K_{20} are fixed limiting values given by the processing plant. The problem is Maximizing the profit by solving the differential equations for P , N_1 , N_2 (Numerically).

The method that we propose in this paper is to find first the "best" mathematical model possible for a specific case by using a new algorithm for automated modelling and then to use a new algorithm for automated simulation to obtain the information needed to find the "best" control possible for the food production process.

4 Method for automated modelling and simulation

We describe in this section a new method to perform automated mathematical modelling for BGCFE using AI techniques. This method discovers the "best" mathematical model for a given food engineering time series using Expert Systems technology¹, and Fractal Theory. We also describe in this section a new method for automated simulation of dynamical systems using AI methodology.

4.1 Method for automated modelling

The problem of automated mathematical modelling can be defined as follows:

Given: A data set (time series) with n data points, $D = \{d_1, d_2, \dots, d_m\}$ where $d_i \in \mathbb{R}^n$, $i = 1, \dots, m$, $n = 1, 2, \dots$.

Goal: From the data set D , discover automatically the "best" mathematical model for the time series.

This problem is not a simple one, because in theory there can be an infinite number of mathematical models that can be build for a given data set, see Rao & Lu¹³. So the problem lies in knowing which models to try for a data set and then to select the "best" one. We can state the problem more formally in the following way:

Let M be the space of mathematical models defined for a given data set D . Let $MA = \{M_1, \dots, M_q\}$ be the set of admissible models that are considered to be

appropriate for the geometry of the data set D. The problem is to find automatically the "best" model Mb for time series prediction.

We consider mathematical models as "dynamical systems" of the following form:

$$dY/dt = F(Y)$$

where Y is a vector of variables of the form: $Y = (Y_1, Y_2, \dots, Y_p)$ and F(Y) is a non-linear function of Y. Other kind of mathematical models are the discrete "dynamical systems" of the following form: $Y_t = F(X)$

where $X = (Y_{t-1}, Y_{t-2}, \dots, Y_{t-p})$ and F(X) is a non-linear function of X. Note that in this case we have deterministic models expressed as differential or difference equations.

The mathematical models for continuous dynamical systems can be one-dimensional, two-dimensional or three-dimensional. We show below some sample models¹² that the intelligent system explores:

a) Logistic differential equation:

$$dY_1/dt = a Y_1(1-Y_1)$$

b) Lotka Volterra two dimensional:

$$dY_1/dt = aY_1 - bY_1Y_2$$

$$dY_2/dt = bY_1Y_2 - cY_2$$

c) Lorenz three dimensional:

$$dY_1/dt = aY_2 - aY_1$$

$$dY_2/dt = -Y_1Y_3 + bY_1 - Y_2$$

$$dY_3/dt = Y_1Y_2 - cY_3$$

The mathematical models for discrete dynamical systems can also be one, two or three dimensional. We show below some sample models¹ that the intelligent system explores:

a) Logistic difference equation:

$$Y_{t+1} = aY_t(1-Y_t)$$

b) Lotka Volterra two dimensional:

$$Y_{t+1} = aY_t - bY_tX_t$$

$$X_{t+1} = bY_tX_t - cX_t$$

c) Henon map two dimensional:

$$Y_{t+1} = X_t$$

$$X_{t+1} = a - X_t^2 + bY_t$$

In all of the above mathematical models a, b and c are parameters that need to be estimated using the corresponding numerical methods.

The algorithm for automated mathematical modelling for prediction is shown in Figure 2, see Castillo & Melin⁶.

STEP 1: Read the data set $D = \{d_1, d_2, \dots, d_m\}$. STEP 2: Time Series Analysis of the set D to find the components. STEP 3: Find the set of Admissible models $MA = \{M_1, M_2, \dots, M_q\}$, using the qualitative values of the time series components. STEP 4: Find the "Best" mathematical model M_b from the set MA using the measures of "goodness" of each of the models from the set MA.

Figure 2 Algorithm for Automated Mathematical Modelling.

The implementation of the method for Automated Modelling as a computer program was done using the PROLOG programming language. The choice of PROLOG is because of its symbolic manipulation features and also because it is an excellent language for developing Prototypes, see Bratko². The computer program was developed using an architecture very similar to that of an intelligent system (knowledge base, inference engine and user interface) with the addition of a numerical module for parameter estimation.

In this computer program, the knowledge base is the part that simulates the process of finding the "best" mathematical model described by steps 2 to 4 in the algorithm of Figure 2. Accordingly, the knowledge base consists of three Modules: Time Series Analysis, Expert Modelling and Best Model Selection.

The Module for Time Series Analysis contains the knowledge to extract from the data the components of the time series. We use a classification scheme, see Castillo & Melin⁸, based on the use of the fractal dimension as a measure of the geometrical complexity of a time series. This scheme is a set of rules relating the value of the fractal dimension of a Time Series to a set of qualitative values for the components.

The Module for Expert Modelling contains the knowledge to obtain the set of Admissible Models considered to be more appropriate for a given problem. This Module consists of a set of rules relating the qualitative values for the Time Series Components to specific Mathematical Models considered the most appropriate.

The Module for "Best Model Selection" contains the knowledge to select the "best" mathematical model for a given problem, i.e., given the set of selected models generated by the step 3 of the algorithm, decide which model is the "best" one to fit the data. In this paper, we are considering as the "best" mathematical model the one that minimizes the sum of Squares of Errors (SSE) for all the Admissible models of the problem. This criteria has the advantage of been valid for all the types of models that we consider in the intelligent system

(statistical models and non-linear dynamical systems models). To give an idea of this method, we show in Table 2 a sample case where the set of selected models is $M_s = \{M_1, M_2, M_3, M_4, M_5, M_6\}$ and the model with lowest SSE is M_4 .

Table 2.- Method for best model selection using the SEE.

Model	Type	Squares Sum	Best Model
$M_1: Y = a_1 + b_1t$	Statistical	SSE_1	no
$M_2: Y = a_2 + b_2t + c_2t$	Statistical	SSE_2	no
$M_3: \ln Y = \ln a_3 + b_3 \ln t$	Statistical	SSE_3	no
$M_4: \text{logistic_differential_eq}$	Dynamical	SSE_4	yes
$M_5: \text{lotka_volterra_difference_eq}$	Dynamical	SSE_5	no
$M_6: \text{lorenz_differential_eq}$	Dynamical	SSE_6	no

In Table 2 the best model is M_4 because $SSE_{\min} = SSE_4$ where:

$$SSE_{\min} = \min\{SSE_1, SSE_2, SSE_3, SSE_4, SSE_5, SSE_6\}$$

The implementation of this minimization procedure is easy once the numerical values of the Sum of the Squares (SSE) are calculated by the numerical module.

4.2 Method for automated simulation

The task of computer simulation of the non-linear mathematical model of a particular dynamical system, is dependent on the appropriate selection of the parameter values to perform the best exploration possible of the dynamical behaviors of the system. The problem of selecting the "best" set of parameter values for the exploration is not a simple one, since it requires using heuristics to develop a set of admissible parameters AP, considered to be appropriate for the given mathematical model, and then using heuristics and statistical calculations to make the final decision of which parameter values are considered to be the "best" set BP. The idea in this paper is that, using AI methodology², the process of parameter value selection described above can be simulated by a computer program, in this way obtaining a useful software tool for the simulation of non-linear dynamical systems. The computer program can be considered an intelligent system, because it shows some intelligent features in simulating the real human experts in the process of parameter value selection described above.

The algorithm for selecting the "best" set of parameter values is shown in Figure 3, see Castillo & Melin⁷.

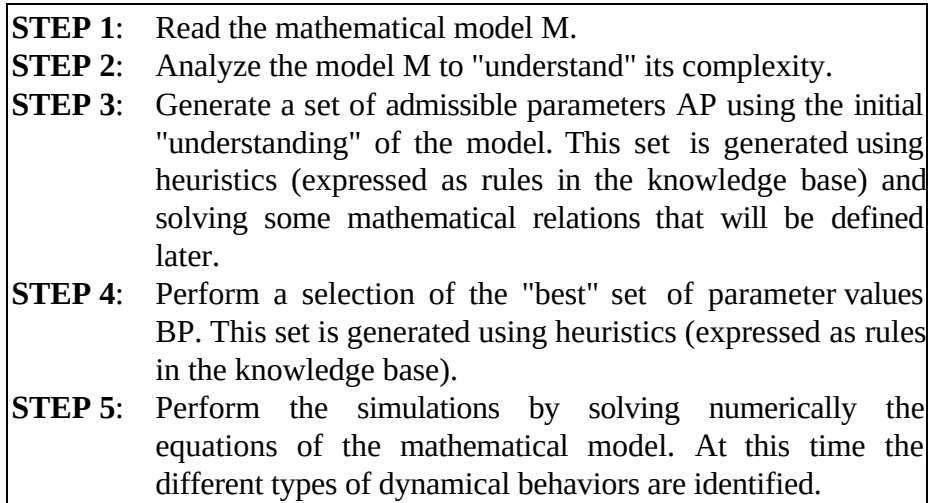


Figure 3 Algorithm for Automated Simulation of Dynamical Systems.

We are considering in this algorithm the "best" set of parameters values for simulation, the ones that enable the correct identification of all the dynamical behaviors for a particular mathematical model. This identification of all the dynamical behaviors is very important because it will help us in the selection process of the "best" control possible for a particular food production problem. The "best" control in this case is found by exploring (by simulation) several possible solutions to the mathematical model and then selecting the solution that Maximizes the Profit as explained in section 3.

The implementation of the method for Automated Simulation as a computer program was done using the PROLOG programming language. The choice of PROLOG is because of its symbolic manipulation features and also because it is an excellent language for developing prototypes, see Bratko². The knowledge base (KB) of the Intelligent System consist of a set of rules containing heuristics and mathematical knowledge about the problem of computer simulation of non-linear dynamical models. This rules were generated by machine learning techniques, using a set of training examples (models). A machine learning program was developed to generate the KB for simulation of dynamical systems. To give an idea of how this knowledge is contained in the KB we will show below some sample rules for several types of dynamical systems.

1) Bidimensional Models: This type of mathematical models can be written in the following manner:

$$X' = \alpha f(X,Y)$$

$$Y' = \beta g(X,Y)$$

In this model, the Equilibria (X^*, Y^*) is stable if: $\alpha f_x + (g_y - \beta) < 0$, where f_x and g_y are partial derivatives. In AI language we have the rule:

RULE 1:

IF $[\alpha f_x + (g_y - \beta) < 0]$ **THEN** Equilibria = stable

Also we have the following rule for a Hopf Bifurcation:

RULE 2:

IF $\alpha_0 = (\beta - g_y)/f_x$ **THEN** Hopf_Bifurcation

We have to note here that the computer program can obtain the symbolic derivatives for the functions in the conditions of the rules. This is critical for the problem of simulation, since we require this derivatives to obtain the values of the parameters α and β .

2) Three-Dimensional Models: This type of mathematical models can be written in the following form:

$$X' = \alpha f(X, Y, Z)$$

$$Y' = \beta g(X, Y, Z)$$

$$Z' = \gamma h(X, Y, Z)$$

In this model, the Equilibria (X^*, Y^*, Z^*) is stable if $a, b, c > 0$ and $(ab - c) > 0$, where a, b and c are defined by the characteristic equation: $\lambda^3 + a\lambda^2 + b\lambda + c = 0$. In AI language we have the following rule:

RULE 3:

IF $a, b, c > 0$ **AND** $(ab - c) > 0$ **THEN** Equilibria = stable

Other rules follow in the same manner for the different types of dynamical behaviors possible for the mathematical models.

5 Method of identification using the fractal dimension

In this section we describe a method for the identification of microorganisms that enables quality control for the food production process. This Quality Control is done by monitoring the types of Bacteria present in samples of food extracted from production lines. We use a method for the identification of microorganisms developed by the authors, see Castillo & Melin⁵, based on the use of the fractal dimension, to eliminate the need of applying a long sequence of microbiological techniques to the samples of food.

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. The problem is then to 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 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 method for the identification of microorganisms using the fractal dimension can be stated mathematically in the following form: let M_m be a one to one map between the sets I_m and D_m , where the set I_m can be called set of identifications of microorganisms and the set D_m can be called set of fractal dimensions. The set of identifications can be as follows:

$$I_m = \{\text{staphylococcus}_{\text{aureus}}, \text{streptococcus}_{\text{fecalis}}, \text{pseudomona}_{\text{aureuginosa}}, \text{salmonella}_{\text{typhi}}, \dots\}$$

and the set of fractal dimensions can be as follows:

$$D_m = \{D_{sa}, D_{sf}, D_{pa}, D_{st}, \dots\}$$

where D_{sa} is the fractal dimension of the Staphylococcus aureus bacteria, D_{sf} is the fractal dimension of the Streptococcus fecalis bacteria, D_{pa} is the fractal dimension of the Pseudomona aureuginosa, D_{st} is the fractal dimension of the Salmonella typhi and so on.

In all of the above the fractal dimension is given by the following definition: $D = [\log(N)/\log(1/r)]$, for an object of N parts each scaled down by a ratio, r . For an estimation of this dimension we can use the following equation:

$N(r) = \beta 1/r^D$, where $N(r)$ = number of boxes contained in a piece of object and r = size of the box. Counting the number of boxes for different sizes and performing a regression we can obtain the box dimension of an object.

The authors have implemented this method as a computer program to obtain an automated method of identification of bacteria, see Castillo & Melin⁵. In this case this method is used to verify the types of bacteria that we have at any moment in our industrial microbiology process, in this way controlling the types of bacteria in the process. This is important for quality control because in some cases harmful bacteria can appear during the production.

6 Validation of the intelligent system

We performed an extensive validation of the algorithms for modelling and simulation for Bacteria Growth Control in Food Engineering using a number of different real food engineering problems. For this test cases, human expert's solutions were known in advance and they were compared to the solutions given by the intelligent system. The results of the computer program were correct for 95% of the cases considered in the validation process. Given this fact, we can say that our methods for AMMS are "sound" and that our implementation of this methods performs with "good" accuracy. However, we have to say that the validation was only limited to the type of models mentioned

in the paper. A more extensive validation process is needed to refine the implementation of the algorithms. Also, we need to increase the size of the set of mathematical models that the intelligent system can explore.

We now show some results of the validation process for the intelligent system. In Table 3 we show the comparison between the Mathematical models (of the Lotka-Volterra type) selected by the intelligent system and the Models given by the human experts in Food Engineering, for a set of specific examples.

Table 3.- Results of the Validation for lotka-Volterra Models.

Food Engineering Problem (time series)	Model by the System	Model by the Experts	Comparison
Yogurt GG	Lotka-Volterra 3-dimensional	Lotka-Volterra 3-dimensional	Equal
Yogurt GGG	Lotka-Volterra 4-dimensional	Lotka-Volterra 4-dimensional	Equal
Cheddar Cheese GG	Lotka-Volterra 3-dimensional	Lotka-Volterra 3-dimensional	Equal
Yogurt GGB	Lotka-Volterra 3-dimensional	Lotka-Volterra 4-dimensional	Different

In Table 3, G is used to denote a "Good" Bacteria, i.e. a Bacteria that is important for the food generation process. But, B is used to denote a "Bad" Bacteria, i.e. a bacteria that inhibits the growth of the other Bacteria present. From the results of this validation, we can see that the computer program predicts very well the exact model for different food engineering problems. However, there are cases where the program fails to find the "best" model, i.e. for the problem of the Yogurt GGB the system should predict a 4-dimensional Lotka-Volterra model instead of a three-dimensional one. In this instance, the system is not able recognize the difference between a "good" bacteria and a "bad" bacteria. We still have to do some work for the knowledge base of the system to refine the process of "best" model selection.

The results in table 3 are only a part of the validation of the modelling algorithm used in the computer program. A similar validation process was performed for the simulation algorithm. The results of both parts of validation are very good in general. However, we still have to make several improvements to the intelligent system. The most important improvement to do for the system is to extend the set of models that the computer program can explore at any moment. This will extend the domain of problems for the intelligent system making it more flexible and more usable.

7 Conclusions

We described in this paper a new method to perform automated mathematical modelling for bacteria growth control in the food industry using AI techniques. Given a food engineering time series, this method obtains the "best" model for the problem. We also described in this paper a new method for automated simulation of the "best" model obtained before. Given the mathematical model, this method automatically performs numerical simulations to explore all the possible behaviors of the dynamical systems.

We have developed a computer program for AMMS using AI techniques for the problem of food production using certain types of bacteria. This computer program (Intelligent System) is the implementation of the methods for automated modelling and simulation described before. The mathematical models capture the dynamics for bacteria population and at the same time of chemical production. The models represent the process of bio-chemical transformation between the microbial life and their generation of the chemical product. The ultimate problem in food engineering is to maximize the production of the food (using the chemical) while satisfying certain constraints. In this paper we have shown how to make more efficient the task of food production in the Industry by using AI techniques. We can conclude then that the use of AI techniques increases productivity in the Food Industry and this also reduces the cost of the food production.

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