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On Line Optimization of an Arbitrary Process by a Personal Microcomputer System: Application in Algae Ponds

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Application of conventional optimal control algorithms requires an a priori knowledge of the mathematical model of the system. However, real systems are seldom simple enough to permit accurate modelling. The purpose of the present study was to investigate possible strategies for on-line optimization of processes which are non linear, time dependent and have no known mathematical model to accurately describe them. It was believed that the dramatic price decrease of microcomputing power can make such an approach feasible in practical applications such as biotechnological production of biomass.
The proposed approach is based on on-line search for optimum operating conditions by a microcomputer system using a modified Simplex algorithm to which several features were added to permit operation in real time. They include boundary limits for variables, noise smoothing and stepwise variations of variables. The on-line Simplex algorithm is simply the upper level of a three level hierarchical program which also includes on-off and PID control (lower level), and an intermediate level of parameter estimation. Experiments were carried out using a microcomputer system which is based on a low cost personal microcomputer, a novel interface for sensors and control devices and battery backup to ensure uninterrupted operation. The method was applied for on-line optimization of biomass production in an algal pond (Spirulina Platensis). The preliminary results seem to support the conjecture that the proposed approach could be useful in optimizing various industrial processes.

1. INTRODUCTION

The strive for process optimization, i.e.: minimization of the cost per product, is universal, reflecting the reality of finite resources as well as that of competition between alternative approaches. Historically, the classical solution to the optimization problem is the trial and error approach through which the best combination of operational parameters for a given process are searched. More sophisticated solutions have been developed of course in numerous control theory studies which investigated various strategies and algorithms for optimal control (1-4). However, all of these require an a priori knowledge of the mathematical model of the system (5) and an almost exact knowledge of its major parameters. In an alternative suggested approach, that of adaptive control, the system's parameters are estimated on line and then used for the formulation of optimal control equations (6-8). However, real systems are seldom simple enough or linear enough to permit accurate mathematical modeling. Furthermore, parameter estimation may not be feasible due to noise, non linearity, and time dependent of the process.

Another approach for solving the optimization problem are the direct search methods in which an a priori knowledge of the mathematical model of the process is not essential. These methods do not apply the derivatives of the function avoiding thereby the mathematical complications encountered is other optimization methods (9) and reduce the problem of data noise which is amplified by differentiation (10). Among the search methods are the"pattern search method" the "method of rotating coordinates" and the simplex method (9,11-13).

The availability of low cost microcomputers makes possible the implementation of on-line optimization by economical, special purpose systems. Using appropriate algorithms, such dedicated machines could serve as "watch dog" for many a processes, tuning the controlling variables so as to optimize the process according to a pre-determined criterion. The purpose of this study was to investigate the problem of on line optimization by the actual setting up of a microcomputer based optimization control system and to test it on a real, complex process.

2. THE PROCESS

The general outline of the problem on hand is depicted in Fig. 1. The objective was to monitor and control a bio-reactor so that it will reach optimum operation condition according to pre-determined criterion which specify the optimization function:

$$F(\text{cost}) = \frac{\text{cost}}{\text{production}} \qquad (1)$$

The "cost" is the sum of the inputs cost whereas "production" is the measure of the total amount of product; all per unit of time. The bio-reactor under investigation was a laboratory algal mini-pond in which the algae Spirulina Platensis was cultivated (Fig. 2). The input variables included: high intensity, nutrients, acid/base for pH control and heat for temperature control. The rate of growth of the algae (the yield) was determined indirectly by measuring on line the oxygen production rate (OPR) by a newly developed method (14). This variable is proportional to the photosynthetic rate. Operational conditions of the algal pond are described elsewhere (14).

3. MONITORING AND CONTROL SYSTEM

The system was built around a low cost personal computer (COMMODORE 64) a general purpose interface and a battery supported power supply to ensure uninterrupted operation (Fig. 3). Details of the interface and signal conditions were given elsewhere (15-17). The system monitored the following parameters: light intensity, optical density, pH, dissolved oxygen and water and air temperatures.

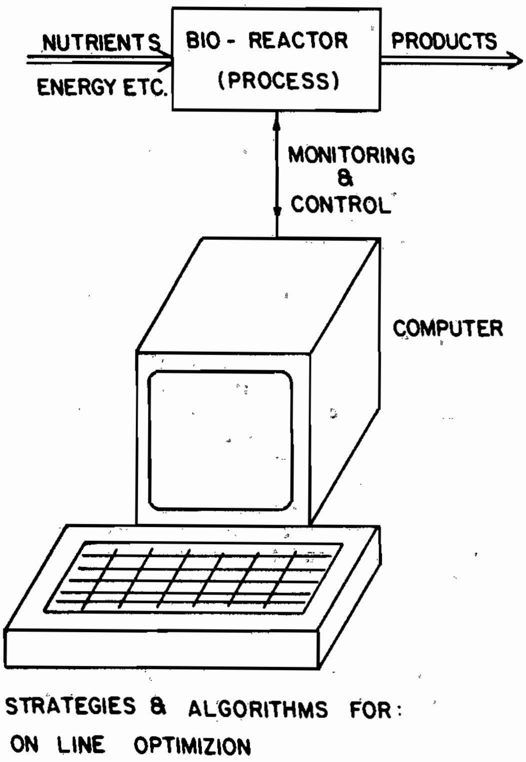

Fig. 1: Graphical representation of the studied problem.

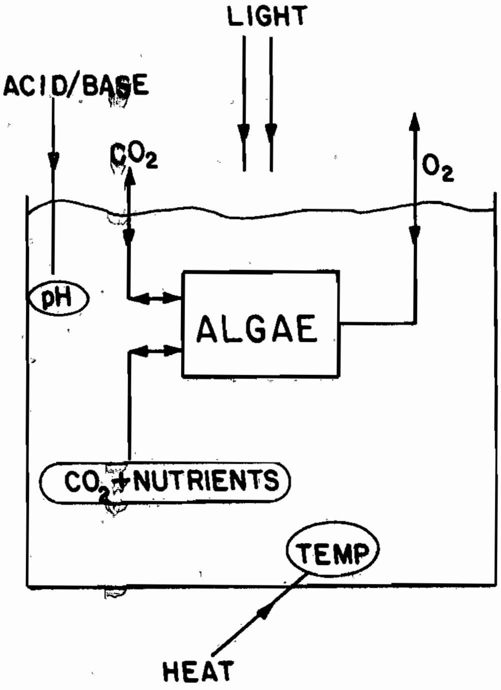

Fig. 2: Main variables of the algal growth process on which optimization was applied.

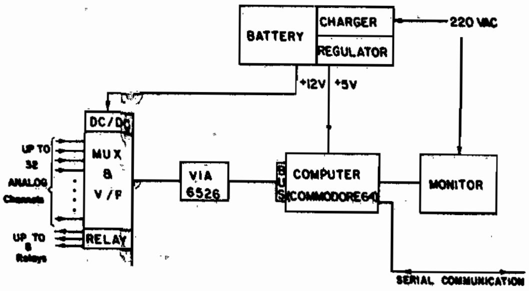

Fig. 3: Block diagram of data acquisition and control system.

The monitoring, control and optimization operation was under the supervision of an hierarchal program consisting of four levels (Fig. 4). The lower levels carry out the basic data acquisition and control operations i.e. sampling, filtering, PID control etc. The intermediate level evaluated the cost function using the data from the lower levels. The search control was carried out by the supervisory part of the program using a modified SIMPLEX algorithm.

4. THE SIMPLEX ALGORITHM

Among the direct search methods, the Simplex algorithm is rather simple to implement on microcomputers since it does not involve massive or complex mathematical manipulation of data nor does it call for a large storage memory. The Simplex algorithm is basically a step by step procedure for locating the minimum (or maximum) of a given function of n variables. That is, an iterative search for locating the point (in n dimension) in which the function, whose analytical form is not known, reaches a minimum. For a two dimension case, the graphical representation of the problem (Fig. 5) is the location of the coordinate (x_1, x_2) at which f(x) reaches a minimum. The search is carried out by considering a polygon with n+1 vertices and replacing them in a systematic way which moves the points toward the optimum point. The method can be illustrated by considering the two dimensional case in which the polygon is a triangle (Fig. 6). The optimization process begins by choosing n+1 points (in this case three points) for which the response is evaluated experimentally. That is, the function (or response of the process) is measured for the three (x_1, x_2) points. If x^h (Fig. 6) is the worst response this vertex is replaced by x^r (reflection), y^c (contraction) or x^e (expansion) points which are located on the line connecting x^h and the centroid x^o. The replacement of x^h by one of the other points is done according to fixed rates which help to choose the point at which f(x) is lower, advancing thereby the searched area toward the optimum point.

5. RESULTS AND DISCUSSION

Several optimization runs were made on the algal mini-pond using the microcomputer based monitoring and control system. The Simplex algorithm was modified to accelerate convergance under the specific operating conditions of the mini-pond, and to avoid damage to the algae by not passing the limits of safe growth environment. Among the implemented modifications:

1. All variables were normalized to the range 0-1.
2. The initial polygon was built to occupy most of the allowed space.
3. Provision was made to reject variables' values outside a predetermined range.

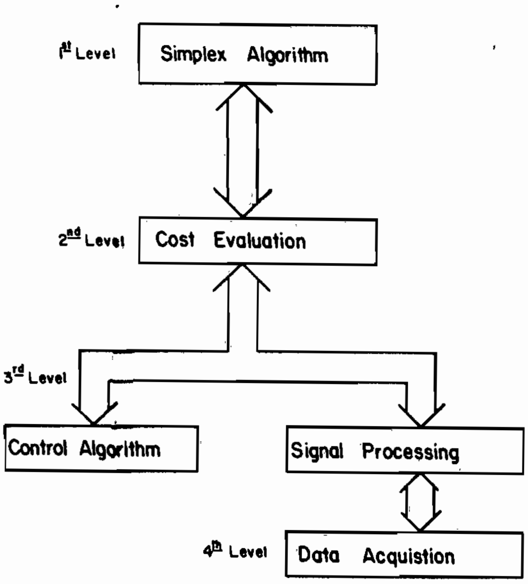

Fig. 4: Hierarchal arrangement of program.

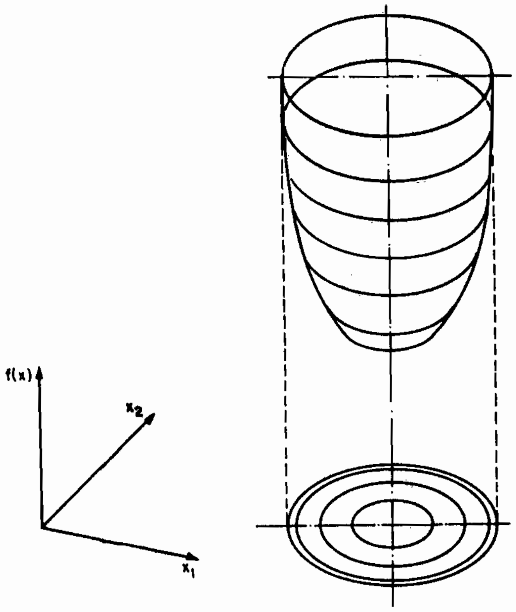

Fig. 5: Graphical representation of the optimization objective in two dimension: to locate (x_1,x_2) for which f(x) is minimum.

4. Function evaluation values which are not coherent with a predetermined criteria are assumed to be more than the worst value in the current polygon.
5. The increment increase in the value of each variable must be greater than a predetermined value.

Data from a typical optimization run is depicted in Fig. 7. In this run, two input variables were considered, light intensity (L) and water temperature (Th). The yield was estimated by the oxygen production rate (OPR) given in units of mg-O_2 produced per liter per minute. The cost function was:

$$F(\text{cost}) = \frac{(\text{Light})\text{x}10^4 + (\text{Temp})\text{x}10^3}{(\text{OPR})^2} \qquad (2)$$

In this experiment, the Simplex algorithm approached the optimum operating conditions within ca.5 steps. Since about half an hour must be allowed between two OPR evaluations, the optimum operating conditions were reached after about 2.5 hours.

The reason for the long delay between the OPR evaluation is inherent in the process of algae growth. The growth rate and dynamics of the system are rather slow with time constants in the range of tens of minutes.

Although the present study was concerned with a specific process: algal growth in a mini-pond, it demonstrates well the feasibility of solving the general problem of on-line optimization. Since the present approach does not rely on an a prioro knowledge of a mathematical model, it is applicable to a multiple of processes both within biotechnology and outside. The only pre-requisite for applying this approach is the ability to measure and control the pertinent variables. It is conceivable that popular personal microcomputers will be sufficient in quite a number of applications in which the processes are slow reacting. The dramatic reduction in the prices of personal micro-computers could make this approach economical not only in industrial applications but also for low production and laboratory units.

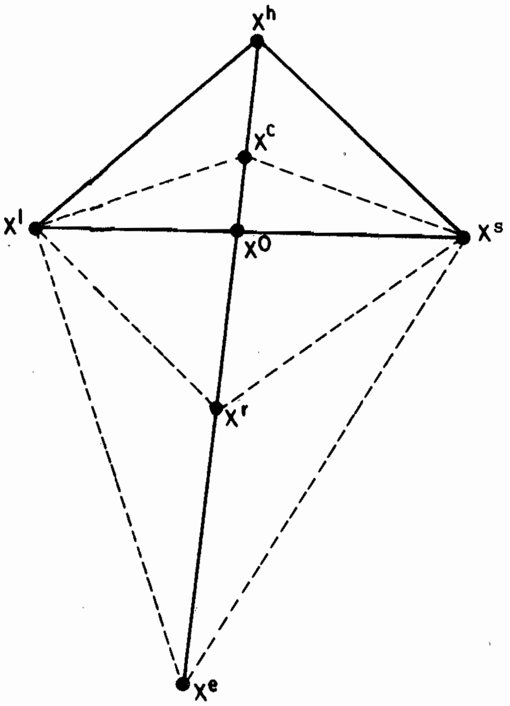

Fig. 6: Graphical representation of the Simplex algorithm in two dimension (see text for more detail).

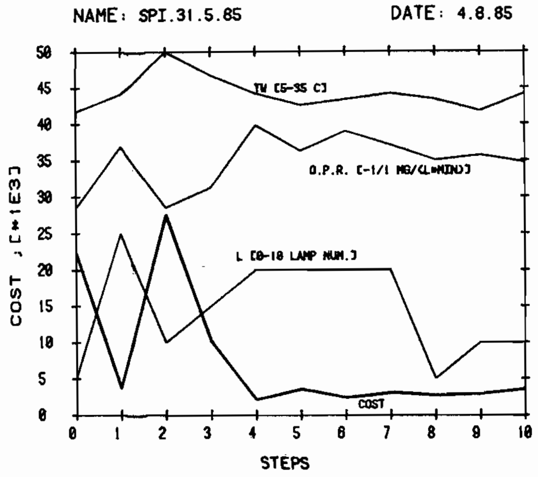

Fig. 7: Optimization of a two dimension Simplex runs. Variables: Light intensity (L) and water temperature (TW). OPR is a measure of growth rate.

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