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# INITIAL EXPERIENCE IN APPLYING QUALITATIVE REASONING TO PROCESS CONTROL

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## ABSTRACT

This work considers the use of qualitative reasoning methods in process control. It deals with single-input single-output systems, using the two coupled tanks system as an example. The basic issues in this field are discussed, and the benefits of combining qualitative and domain specific quantitative knowledge demonstrated.

## I. INTRODUCTION

Qualitative reasoning methods have been used in the simulation of the behaviour of physical systems [1], [2], [3]. Recently these methods have been investigated in relation to process control with the object of overcoming some of the problems that stem from the inadequacies of numerical modelling. In particular, the need to provide exact numerical values for the parameters of the differential equations describing the dynamics of physical systems, and the failure of numerical modelling techniques to adequately model the system over the full operating range, are of great significance [4], [5].

The qualitative reasoning approach is different from the conventional shallow knowledge expert system methods. The shallow knowledge method, which is also known as "Expert Control" [6], uses the knowledge of the expert plant operator, to modify the settings of a conventional controller. Qualitative control on the other hand depends on the deep knowledge extracted from the understanding of the physical interaction between the different components of the plant. This knowledge is used to construct a qualitative model that is used in the control operation. A useful comparative study that shows the advantages and the disadvantages of both methods is presented in [7].

A qualitative controller has the potential to overcome the tuning problems and the effects of nonlinearities which can occur when a conventional PID controller is used and tuned according to conventional methods.

## II. METHODOLOGY

The qualitative control methodology described here concerns single-input single-output processes. The problem is approached by considering the process as a series of sub-systems, each of which is identified by a state variable that can take one of several possible qualitative values. Here we take (+, 0, −) as the set of all possible values. Therefore the sub-system i, for example, can be represented by the variable Xi, which can take a value of (+), (0), or (−), at any instant in time.

The nature of the dynamic interaction between any two adjacent sub-systems is then considered. By adjacent sub-systems we mean any two sub-systems where the change in the variable representing one of them causes a direct change in the other. In qualitative terminology this interaction can either be a monotonically increasing or a monotonically decreasing function. Here we use the same terminology introduced by Kuipers [3], where a monotonically increasing relationship means that one variable increases as the adjacent variable increases and vice versa. This can be represented by;

X2=M−plus(X1).

Figure (1) shows two sub-systems with an increasing relationship. A decreasing relationship on the other hand refers to the case where one variable decreases as the result of an increase in the adjacent variable and can be represented by;

X2=M−minus(X1).

A process can thus be represented as the effect of each of its sub-systems on its neighbour as shown in figure (2).

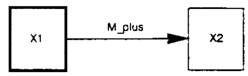


Fig. (1)
Subsystems with an M_plus relationship

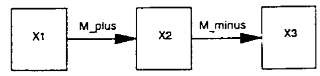


Fig. (2)
Process representation

For two adjacent sub-systems with an M-plus relationship, we can introduce a set of control rules with the objective of controlling the value of X2 by using X1 as a contol variable. These rules are derived by common sense reasoning and they state the value that X1 should acquire in order that a specific state transition of X2 from an old to a new qualitative value can be achieved. Table (1) shows these control rules.

| X1 | Old X2 | New X2 |
|---|---|---|
| * 0<br>+ | + | + |
| − | + | 0 |
| − | + | − |
| + | 0 | + |
| 0 | 0 | 0 |
| − | 0 | − |
| + | − | + |
| + | − | 0 |
| * 0<br>− | − | − |

Table (1)
Control Rules

The situations involving the transition of X2 to, or from a (0) state are straigtforward, so are the cases in the (+) to (−), and the (−) to (+) transitions. However, two possibilities arise when it is required to maintain X2 at a (+) or a (−) state as shown in the first and the last rows of table (1). We reason here that to keep the value of X2 at a (+) or a (−) value, it is better to stabilise the value of X1 at a (0) state. This is done in order to prevent uncontrolled increases or decreases that might lead to the quantitative limits imposed on the physical system being exceeded. This is typical in the problem of the two coupled tanks where it is required to prevent water overflow. Thus we choose the options marked by a star in the first and last rows of table (1), to leave a final set of nine control rules that govern the interaction between the two sub-systems. A similar set of rules has been defined by other researchers [4], [5], although different reasoning methods were used especially when more than one possible action exists.

## III. THE APPLICATION

The method is applied to the two coupled tanks system, shown in figure (3), to control the level in tank 2. The process is considered as four sub-systems identified by four variables. These are the pump voltage input, the rate of change of level in tank 1, the rate of change of level in tank 2, and the error in the level in tank 2 with respect to a set point. The model is shown in figure (4).

The basic qualitative controller uses the knowledge of table (1), as follows. The levels in the two tanks are sampled at a fixed sample-action interval. The qualitative error value is established by comparing the level in tank 2 with the set point, while the rate of change of the two levels is found by reference to the history of the levels. The procedure then works backwards through the sub-systems applying the control rules of table (1), to determine the required state of their variables that would achieve a (0) error state. The final application of the

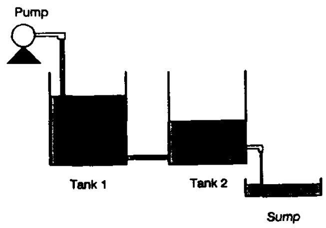


Fig. (3)
The Coupled Tanks System

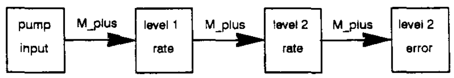


Fig. (4)
The two tanks model

rules gives the required state change in the pump input. The pump input is changed by applying a predetermined incremental change to the pump control voltage. Figure (5) shows the response of the level in tank 2 to a step change in the set point using a sample–action interval of 0.5 second and a voltage increment of 0.1 volt.

The response can be greatly improved both in transient and steady–state behaviour by combining the basic qualitative controller with domain specific quantitative knowledge. Two important quantitative values are the time history of events required to evaluate the qualitative values of the rate of change of levels (we refer to this time as the "Trend Interval"), and the practical rates of change of the levels. Some experimentation is required to obtain the combination of these two values with the sample–action interval and the voltage increment that gives the best possible control result. The response of the level in tank 2 for the same previous step change in the set point with the improved qualitative controller is shown in figure (6), while figure (7) shows the response using a well tuned PID controller for comparison.

## IV. Conclusions

Previous research has shown that a controller based on a pure qualitative model can achieve the control objective of maintaining the level in the second tank steady at the required set point. But, this controller is inefficient, as demonstrated in figure (5), due to its slow transient response and oscillatory steady–state. These drawbacks are natural consequences of the generality and simplicity of the qualitative model.

A combination of simple qualitative modelling and domain specific quantitative knowledge can cure the drawbacks of the basic qualitative controller. The process of identifying the significant quantitative parameters and their values requires some experimentation. In relation to the two tanks problem we have identified the "Trend Interval" and the practical rate of change of levels as important parameters in addition to the sample–action interval and the voltage increment. The resulting performance is comparable to that of a PID controller.

More research is required to establish whether the use of qualitative controllers is justified in situations where a quantitative controller is difficult to tune.

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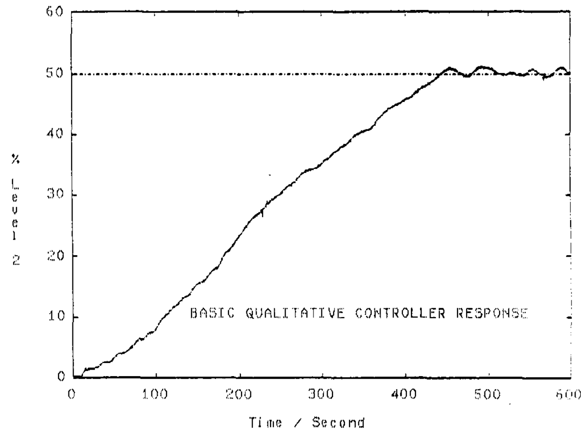


Fig. (5)

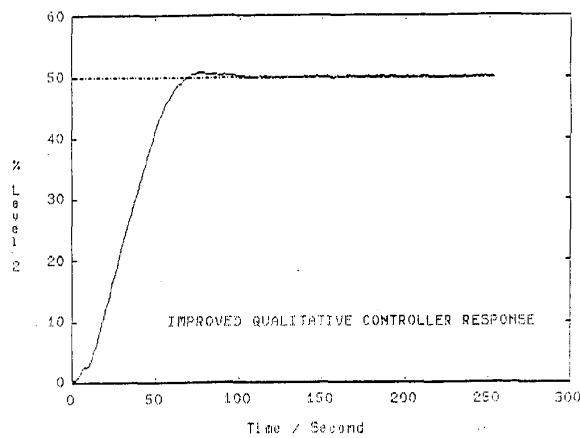


Fig. (6)

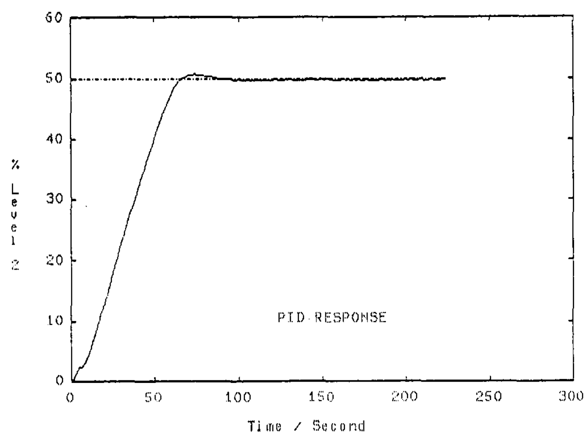


Fig. (7)