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New bio-process control scheme: Decentralize autonomous control system

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Abstract: It is not so difficult to design a fully automatic control system for the chemical plant, if control engineers and instrumentation engineers understand the static and dynamic characteristics of that plant. However the behavior of those plants specially so-called bio-plants is not easily measured and understood. If a plant in an organization does not perform a vital role or dose not require very accurate control, a relatively simple control system, i.e. only to maintain the plant at its current state or prevent it from moving into abnormal states, may be sufficient from point of view of reducing the operative personnel. The aim of this study is to establish the effectiveness of the autonomous control system for such a situation.

Keywords: autonomous control, bio-process, decentralize, self control system

1. Introduction

There have been many remarkable improvements in the control scheme or systems, since the development of computer and communication technology. However, these improvements are still mainly in the systems with linear or well-known characteristics such as petroleum refineries or petro-chemical plants. When a system like the autonomous system is developed, we can expect further improvements in process control for bio-process plants or other chemical plants, whose characteristics we do not exactly understand. The autonomous control system can be realized on computer networks or on a decentralized computer system.

The aim of this study was to examine the effectiveness of the autonomous control system for the plants which do not perform a vital role or do not require very accurate control, a relatively simple control system.

To make the autonomous condition establish, the “Happiness Index” is introduced. This concept has been applied onto and tested for an example process case by simulation.

2. Image of autonomous control system

2.1 *Comparison with advanced control*

At least two ways will be considered to control a plant in fully automatic condition. One is the top-down type advanced control system, now widely adopted by the chemical industry. The other is the autonomous system which will be applied in the future(Fig.1).

When considering the efficiency of controlling, a top-down system can realize faster and more efficient performance. This is because a top-down system can be established only when total condition are known by the ‘top’, which directs the system. In contrast, in an autonomous system each control segment works independently. Consequently, the results from the summation of each segment’s action are very hard to predict, and one can only hope for the best. For this reason, the autonomous system would be suitable for a process which requires only a sub-optimal control result, because of its vague characteristics.

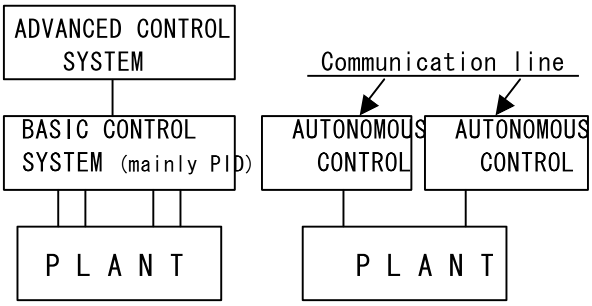


Fig. 1 Advanced vs. autonomous control

2.2 *Relation with Fieldbus*

Fieldbus is the new technology available for plant control, now gradually known among instrumentation engineers.

The structure of Fieldbus is very close to autonomous system, although still its capability does not so high to install autonomous system. If the elements of Fieldbus system will have enough capability in the size of memory and calculation power, this can be easily converted to an autonomous system.

3. Proposed autonomous control system

In constructing an autonomous system, the following demands were made by Prof. Shin et al. in 1995.

(1) Each unit was programmed for independent, individually control section.

(2) Each unit had the same structure in principle.

(3) Each unit had equal rights; there were no master- nor slave-like relationships between the different controllers.

To realize this, the principle of ‘Agents’, now gradually becoming popular in the computer software and network communication fields, was adopted. One Agent can communicate with others, can infer its own status, and can have the same structure as the others. To infer, judge and decide what should be done, an Agent needs to have a criterion or objective function. For this purpose, in the present system a 'Happiness Index' (HI) was introduced. Each Agent should be 'happy' with its decision making, with a higher value of HI. In the present work, a 2nd order function of the form Eq.(1) was used for HI, as schematically illustrated in Fig.2.

$$HI = 1/A \times X \times (2 - X/A) \qquad (1)$$

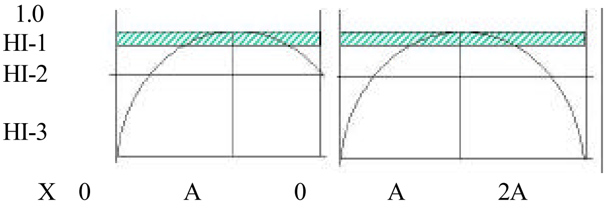


Fig. 2 Form of Happiness Index

where X presents any process variable taken by an Agent. This means that extremely low or high values are not recommended, and an HI around the normal value (A) which is decided by the process engineer or by common sense for the plant under investigation may be kept, for example, within 0.9 and 1.0 (zone HI-1 in Fig.2). If an Agent has multiple inputs, HI can simply be averaged, or a weighted average can be taken when appropriate.

4. Programming environment

In the present work, each Agent described was built as a software programmed model, and the behavior of the Agents was investigated by simulation. The knowledge and functions of all Agents were programmed by using the SmallTalk programming environment, and the simulations were carried out using a Macintosh SE/30 system J7.1.

5. Example process

To demonstrate the efficiency of the autonomous system, an example bio-process with a flow-sheet given in Fig. 3 was employed for the simulation. This process involved the separation of a gas phase bio-product (bio-prod-A) from a liquid phase bio-product (bio-prod-B). As illustrated in Fig.4. the example bio-plant was divided into seven major functions. Of the 7 Agents designed for the respective functions, 4 (Biomat Tank, Steam, Bio-prod-A, Bio-prod-B) had the capability to control the plant. The feed liquid flow was controlled by a flow controller (FC-1) and the temperature by two heat exchangers (H-EX 1 and 2). Two more Agents were programmed to communicate with the control Agents, with the control commands to improve their respective HI. Further, all Agents had the ability to improve their own HI. The relationships between the Agents are shown in Fig.5. Each Agent was given the necessary basic knowledge related to the appropriate function. For example, the Agent representing the bio-reactor (Bioreactor Agent) was given the desired values of pressure, temperature, and the level in the bioreactor. Bio-prod-B Agent was also programmed to communicate with the other Agents, like the Bio-reactor Agent and Hex-1 Agent. Making use of the communicating functions, Bio-prod-B Agent could, for example, ask Hex-1 Agent to display the value of temperature, and Bio-prod-B Agent could follow the order of the Bio-reactor Agent to close or open a valve.

In the biochemical reactor (R-1), the substrate feed liquid was activated and changed into the products Bio-prod-A and Bio-prod-B. Four controllers were used to maintain the plant under the desired conditions. Under normal operating conditions, feed liquid temperature (T-15) could be easily controlled. For simplicity, the disturbances investigated during the simulation were limited to insufficient heat being transferred by the steam system and, as a consequence, bio-reactor temperature (T-17) would fluctuate around the set point. Under such conditions, bio-reactor pressure and the ratio of Bio-prod-A to Bio-prod-B would be expected to be changed with changing bio-reactor temperature.

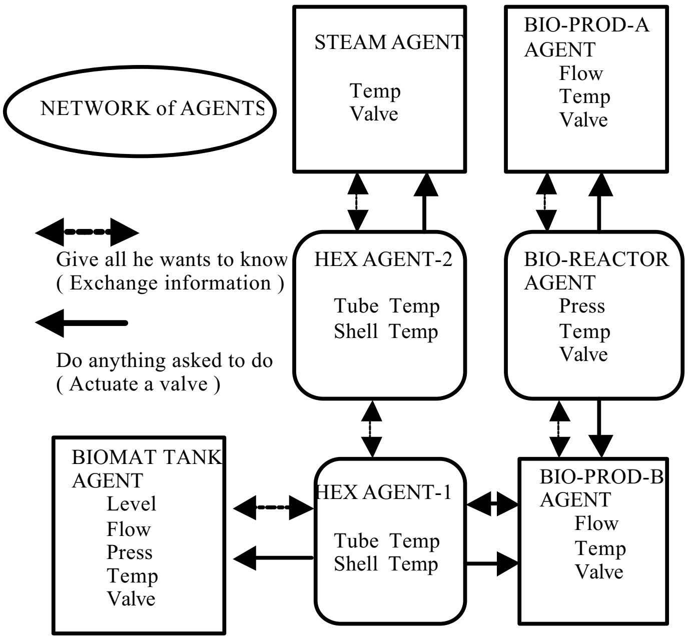
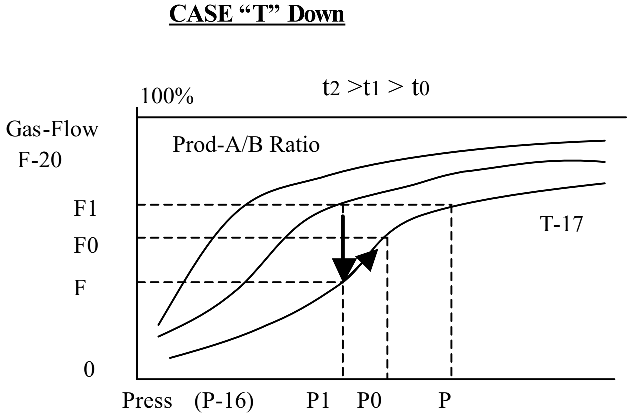


Fig. 5 Network of Agents

6. Simulation results

A simulation for a temperature change in the bio-reactor (R-1) is presented here as an example. The results are illustrated in Figs 6 and 7. When the bio-reactor temperature (T-17) was decreased from T1 to T0, the system of Agents, other than the Steam Agent, cooperated in order to carry out the necessary control actions. If the pressure (P-16) would remain unchanged at P1, gas flow (F-20) would decrease to which is not, in the example case, a happy condition for Bio-reactor and Bio-prod-A Agents (Fig. 6) Consequently, the Bio-reactor Agent tries to maintain bio-reactor pressure (P-16), and Bio-prod-A Agent



$[HI(P,F_1),HI(P_1,F)] \rightarrow HI(P_0,F_0$

Fig.6 Explanation of simulation result reacts to the request of the Bio-reactor Agent to increase gas flow by actuating a valve through the gas flow controller. To increase the bio-reactor pressure the valve position should be solved by the Bio-prod-A Agent, resulting in the new conditions (T0, F0, P0) for the bio-reactor.

Fig. 7 shows the actual simulation result, which was rapid– within 2-3 time units – both for the pressure and gas flow. Because the Steam Agent did not react in this case, no correction of bio-reactor pressure and gas flow, one could expect that an even longer disturbance in the bio-reactor temperature would have little effect on bio-reactor stability.

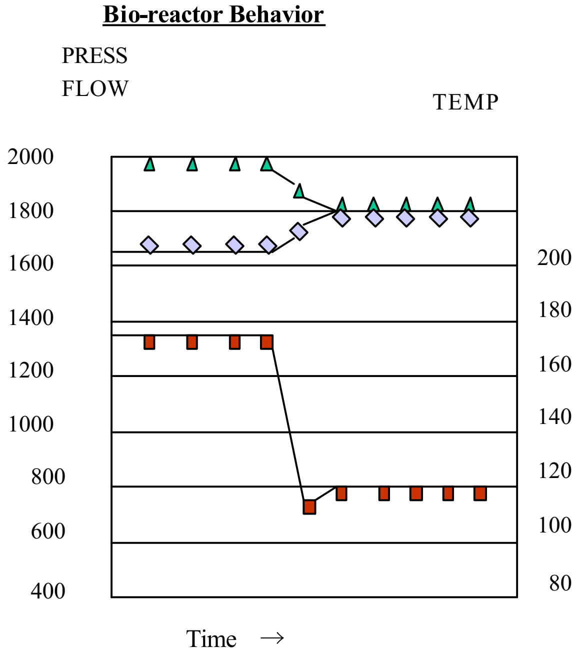


Fig.7 Simulation results

7. Discussion

With the advanced, decentralized autonomous control system installed, desired bio-reactor conditions could be satisfactorily maintained and disturbance related problems prevented. Although a relatively simple bio-process simulator was employed for this preliminary study, the results obtained were quite promising. Nevertheless, the several questions still remain open.

Is there any possibility of upset of the control system? Is it possible to stop the overrunning of the control? Apparently, if the system were not given an appropriate objective function or HI, the control system would be likely to fail. In addition to HI, an Agent could have further knowledge about the system, i.e. a value above the maximum limit is not good, or under some conditions no action by the Agent itself is required except for asking help from one or more of the other Agents, which would prevent the system from being upset.

To what extent is this system stable? How fast will it settle? These questions are not easy to answer, and the answer depends on the knowledge of each Agent. If the Agent fail to cooperate with each other, what would the final outcome be? Clearly, the result could be a mess. All Agents would continue to fluctuate around certain values. Arriving at such an unstable situation could be prevented by special command actions by the responsible Agents.

Could the system benefit from the introduction of a supervisory or patrolling Agent? According to the initial definition, all Agents should be independent with equal rights. In this sense, a supervisory Agent would not be allowed, but if a supervisory Agent is constructed to give others overall or summarized information about the whole plant, this would still fall within the definition. In such a case, a supervisory or patrolling Agent would be useful for rapid settling in case of unexpectedly large upset.

8. Conclusions

A novel concept for autonomous control system has been proposed. Although the preliminary results from simulations are promising, much more work is needed in order to conclude its effectiveness in real-life situations. However, especially for a plant of which characteristics are only roughly known as is often typical for such as a bio-process, the concept proposed could be quite useful as compared to conventional control methods based on linearity and the transparency of the system. Further, a decentralized system utilizing communication technology and the capability of micro-chip computers can result in considerable savings in engineering design work, especially by employing the same structure of the control software for each Agent.

For some years before, the phrase “hito-ni-yasasii” (HNY), meaning operator friendly, easy to operate or safe operation even with less operators, had been very popular. To realize this HNY system, is still challenging object. It is requiring very high techniques are required. The requirements to reduce the number of operators, to employ non-skilled operators or to operate without operators will continue to increase, requiring high technology and skilled engineers to realized the necessary control system. Further, deeper knowledge about the process is essential for establishing a good operating system. However, these requirements are not always easy to fulfill and, consequently, an autonomous system described would be useful in HNY control of the some sort of a plant such as the bio-plant.

In real world applications, each Agent could be represented by a PC computer or work-station depending on the functional scale of the Agent and the computing speed required in the system in which the Agents are applied.

Acknowledgement

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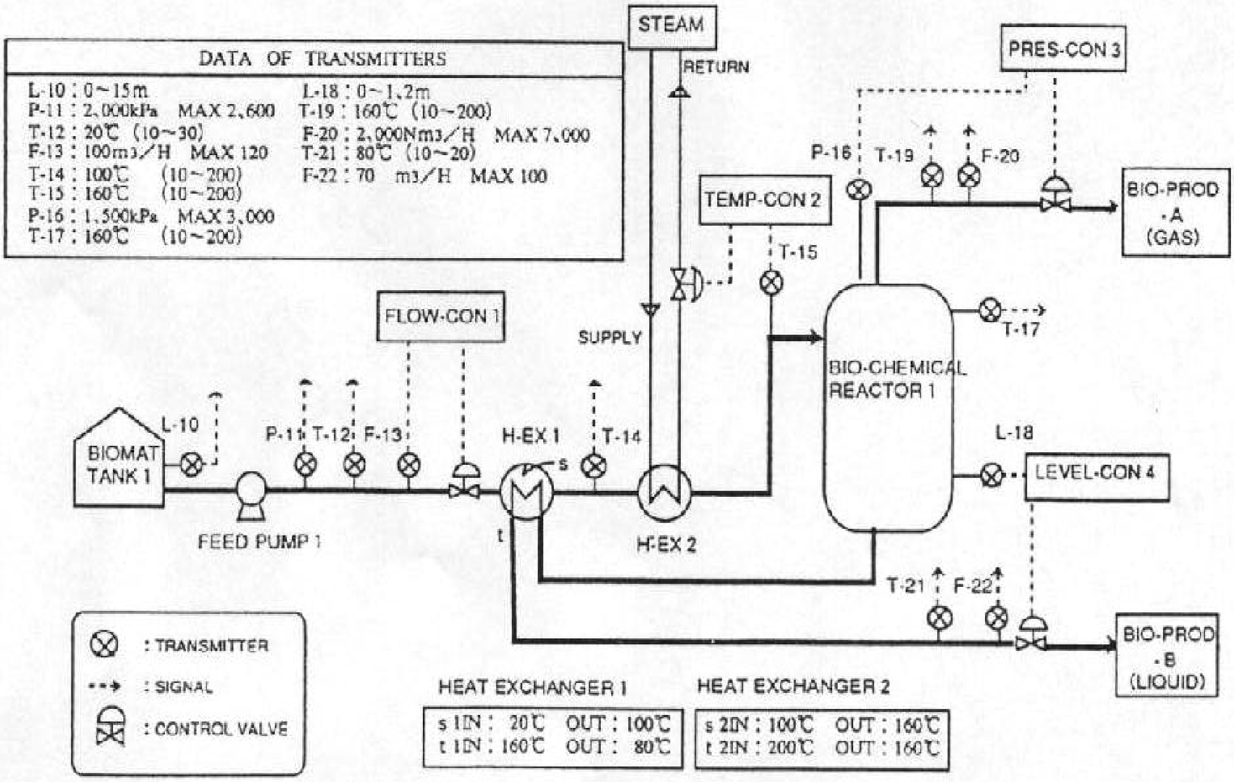

Fig. 3 Example bio-process plant

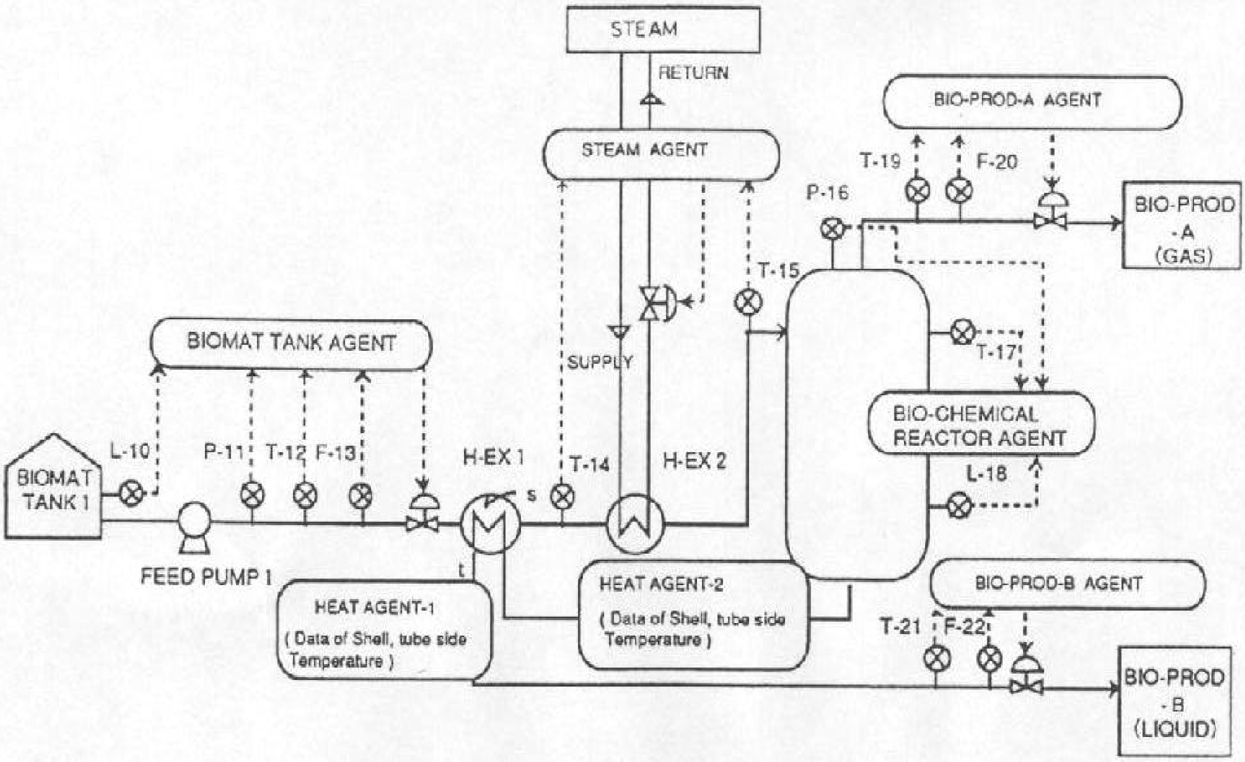

Fig. 4 Responsibility covered by each Agent