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A New Concept of Control System

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ABSTRACTS

In the field of control technology, too, it is about time that the students should free themseleves from the paradigm of Newtonian mechanics. Otherwise, they might fail to grasp the essence of control

Now, let us consider the essence of control. Control consists of manipulating a particular object, matter, energy of environment on the basis of certain medium information. (measurement data, force, etc. ......) So, we shall look into the methods of manipulation. Here, we consider natural control, constraining control, and hybrid control as basic methods of manipulation.

In this paper, we would like to put forward the daring proposal that it's called a Holon-type hybrid control system. It is intended to control a plat with complicated or unknown characteristics where a conventional control theory is not easy to apply. A prototype system has been developed and applied to a real plant.

The control system is a multi-layer system. Each layer includes different control input. The important features of the system are as follows:

1) Each layer behaves autonomously and also cooperates with each other to optimize the whole plant.
2) The controller optimizes a plant without mathematical models when these models are not easy to obtain.

1. Introduction

Steel manufacturing processes consist of, in order of material flow, raw material processing (such as sintering, coking, iron-making, and steelmaking), reheating, rolling, etc. Classical and modern control theories have been widely applied for controlling these processes. However, a major problem is that processes with complicated or unknown characteristics, particularly in raw material processing, are often hard to express by mathematical models, hence, hard to deal with adequately for a controller based on such models. From this point of view, we propose a new control system called a "holon-type hybrid control system". A prototype system has been developed and applied to a heat recovery plant after sintering process. Control algrorithms and some results obtained from on-line control are described in this paper.

2. Holon-type hybrid control

In recent years, the word "holon" has creted a sensation in many different fields, such as science, engineering, and business management. When a system has such a property that its each element behaves autonomously, and also cooperates with each other to optimize the whole system, an element of the system can be called a holon. We tried to introduce this property into process control to form a "holon-type hybrid control system", in order to solve the control problem mentioned in the previous chapter.

Fig. 1 shows a new system. In Fig. 1, a controller is divided into several layers. Each layer includes different control inputs to a plant, and has its own control law and a learning mechanism. Each layer behave autonomously, keeping some restrictions to maintain a normal operation. These layers are arranged from the top to the bottom in descending order of control intervals. Higher layers mainly employ feedforward control to cope with slowly-changing disturbances into a plant, while lower layers mainly employ feedback control for faster changes under circumstances determined by higher layers. This control system is holon-type bacause each layer works autonomously in hierarchical structure. It is hybrid because of the difference in a control law between higher and lower layers, i.e. feedforward control at higher layers and feedback control at lower layers.

The control results are evaluated by the system itself or by human operators. The results of evaluation are then sent back to a learning mechanism at each layer. The learning mechanism changes a control law to optimize control inputs at each layer, which, if this multi-layer structure is adequate, leads to the optimization of the whold system.

Many conventional control systems are multi-layer systems, but they are different from the system shown in Fig. 1 in the sense that the top layer dominates the whold system, sending instructions to lower layers. on the other hand, the main property of the system in Fig. 1 is that each layer is largely independent, and influences on others mainly through a plant.

3. Plant for on-line experiment

In other to verify the effectiveness of this system, a heat recovery plant after sintering process was chosen for on-line experiment. Fig. 2 shows the plant scheme. The plant generates electric power from the heat in sintered ore.

In this plant, sintered ore is cooled from 400-600°C (just after sintering) down to under 100°C by compulsive air circulation while it is carried on a conveyor. The conveyor is divided into two parts, #1 and #2 zone, as shown in Fig. 2. The air flow is described as follows:

First, under #2 zone, #2 cooler blower (#2, CB) sends the air into #2 zone. The air is heated up to 150-200°C and sent to #1 cooler blower (#1 CB). This air is then mixed with the fresh air and goes through #1 zone, heated up to 250-350°C. This hot air, called the hot gas, is sent to a boiler to exchange heat energy, and is finally discharged into the atmosphere by an induction fan.

For the control of the plant, the following two were chosen as control inputs:

1) Set point of mixed air temperature at #1 CB (for the higher layer).............(TA3S)
2) Revolutions of an induction fan after the boiler (for the lower layer).......(REC).

TA3S is a set point to a conventional controller to control the mixed air temperature mainly by manipulating a valve for taking in the fresh air before #1 CB. Therefore the reduction of TA3S causes the increase of the flow rate of this fresh air, hence, results in the increses of the flow rate of hot gas after #1 zone (FA5). FA5 also changes proportionally to the change of REV. The change of REV results in the changes of the flow rate of both the hot air and the fresh air at #1 CB.

The purpose of control is to maximize the plant output, electric power. The output is expressed by a flowing equation:

Where Q_E is the output, Q is the heat contained in sintered ore, T is the production rate, and , and efficiency factor, is a function of particle size, the atmosphere temperature, the mized air temperature, the flow rate of hot gas, the heat in sintered ore, etc.

Thus, the output is influenced by many disturbances and process variables. The relationship between the output and those influencing the output is so complicated that it is not easy to develop an adequite mathematical model for on-line control. Among the disturbances, values of the following three can be obtained on-line to be put into the control system:

1) Temperature of sintered ore at the entrance of #1 zone .... (TS1)
2) Atmosphere temperature .... (TAC)
3) Production rate .... (PR)

TS1 is almost linear to Q in equ. (3.1).

A mathematical model of a plant was developed for this experimental case to investigate a plant and a control system. By using this model, simulations of plant behaviors for various cases were carried out with an off-line computer.

Fig. 3 shows some of the results obtained from the simulations. It shows how the generator output, electric power (PWR), is affected by the changes of the mixed gas temperature (TA3S) and the sintered ore temperature (TS1). The output has a peak corresponding to an optimal value of TA3S, which changes according to the changes of TS1.

4. Control algorithms

Fig. 4 shows a prototype of a holon-type hybrid control system for a heat recovery plant. The main feature is that the controller searches for the optimal values of control inputs to maximize the output, electric power, by its learning mechanism without any mathematical models.

As shown in Fig. 4, the controller consists of two layers. The upper layer (layer 1) is to cope with slow plant fluctuations mainly caused by order to search an optimal value of the control input (TA3S), the controller of layer 1 chooses the value of TA3S stochastically according to a probability table and put it into a plant. Each value in the table corresponds to a value of TA3S and represents the probability for the corresponding value of TA3S to be chosen. The probabilities are updated according to the result in the previous control interval so that the value of TA3S producing a larger output is given a higher probability to be chosen. Since an optimal value of TA3S changes depending on the disturbances, the disturbance space is divided into small cells and layer 1 has the same number of probability tables as the number of cells. One table corresponds to on cell.

By this algorithm, the controller eventually chooses an optimal value most frequently but sometimes chooses different values. This fluctuations of control input, TA3S, enables the controller to catch the changes of an optimal value of TA3S caused by some unknown disturbances.

Next, the lower layer (layer 2) searches for an optimal value of REV by a dynamic hill-climbing. If the increse of REV had resulted in the increase of the output, electric power, REV is again increased for the coming control interval. Thus, layer 2 optimizes a plant under any circumstances determined by layer 1.

5. Results from on-line control

The control described in the previous chapter has been applied to a real plant at Kimitsu Works of Nippon Steel Corporation for several months. Fig. 5 shows a typical plant behavior. As for control Actions, the following things have been mainly observed:

1) When there is an increase in TS1, the control input at layer 1, TA3S, is reduced to increase the flow rate of hot gas (FA5).
2) When there is an increase in TA3S, the control input at layer 2, REV, is reduced to decrease FA5.

The above actions are marked in Fig. 5. Both the off-line simulation mentioned in chapter 3 and on-line observation has confirmed that these actions lead to increase the output, electric power: Fig. 3 shows that action 1) is reasonable because an optimal value of TA3S in Fig. 3 decreases with the increase of TS1; similarly, action 2) is also shown reasonable by another simulation result (not shown in this paper).

Action 1) above can be considered as an effect of learning at layer 1. Action 2) indicates that layer 1 influences layer 2 through the plant and layer 2 behaves cooperatively with layer 1 to increase the output.

As for the control effect, the output, electric power, has increased by about 10% compared with manual operation before the application of this control. Thus, it can be said that this prototype system has been proved effective in the control of this real plant.

The main remaining problem is that the leaning at layer 1 is not so efficient. Particularly when the number of cells in the disturbance space is large, the learning process is likely to take a long time.

6. Conclusions

A prototype of a holon-type hybrid control system has been developed and applied to a heat recovery plant after sintering process at Kimitsu Works. The prototype has been proved effective. The increase of about 10% in the output, electric power, has been achieved through on-line control. This figure was beyond the performance of experts among human operators, which may suggest that this type of control can behave better than a control based on a expert system.

In order to achieve an optimal control, many conventional multi-input control systems determine all the optimal values of control imputs simultaneously by using mathematical models, which are often hard to obtain. On the other hand, a holon-type hybrid control system optimizes a plant with the optimization at each layer.

The important features of this system are as follows:

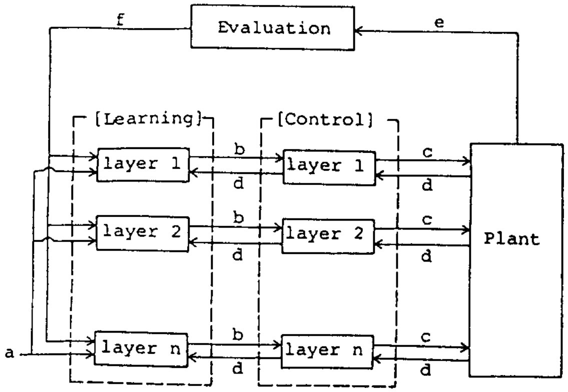
1) Each layer behaves autonomously and also cooperates with others to optimize the whole system
2) The controller optimizes the system without mathematical models when these models are not easy to obtain.

These features lead to the following advantages in practical applications:

a) The controller is likely to be able to optimize many of such plants where a conventional control system is difficult to apply because of the complicated plant characteristics and the difficulties in developing mathematical models.
b) The controller design and development can be made comparatively simple and easy.

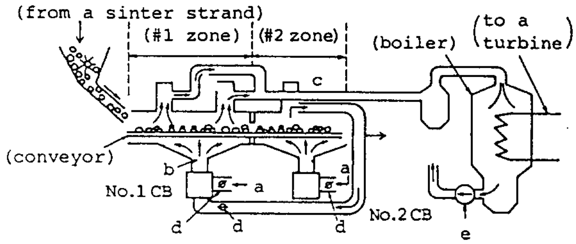
The above a) does not mean that, this type of control totally excludes a convetional (classic or modern) control. A holon-type hybrid control may include a conventional control at some suitable layer. Also, it may include an expert system at a higher layer for high-level decision making or other.

Although a prototype controller has been successful, further improvements and developments on, such as, more efficient learning mechanism etc. are necessary for broad applications of this control.



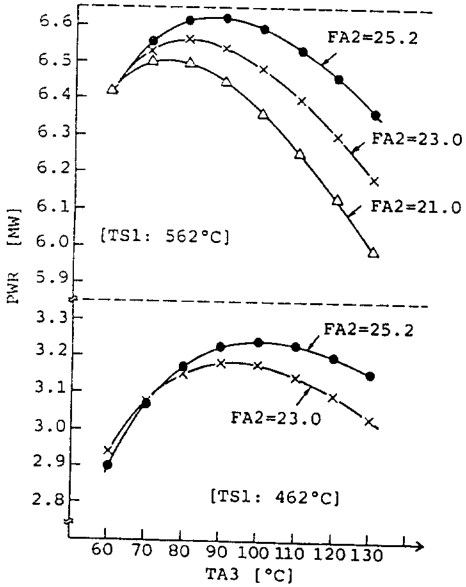
a: disturbances b: control law
c: plant input d: observations
e: plant output f: evaluation results

Fig. 1 Holon-type hybrid control system.



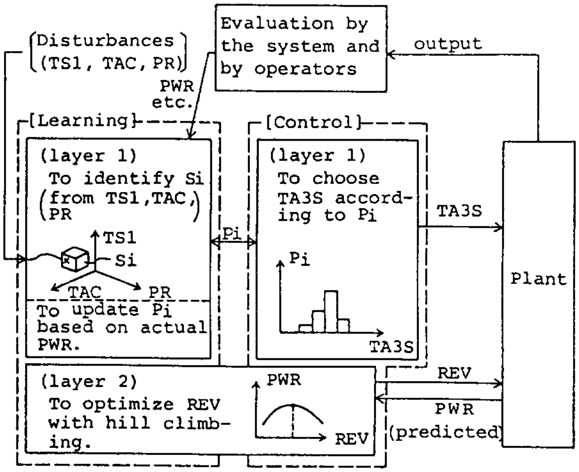
a: fresh air, b: mixed air, c: hot gas,
d: valves, e: induction fan

Fig. 2 Heat recovery plant after sintering process.



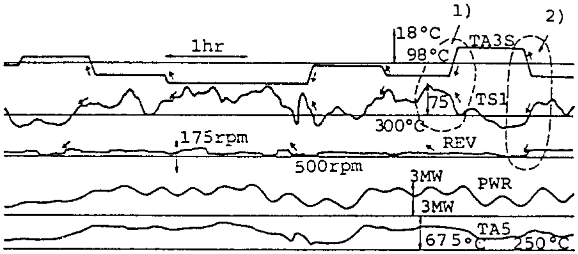
TA3: mixed air temperature (°C)
PWR: generator output (MW)
FA2: flow rate of hot air after #2 zone (10^4 Nm³/h)
TS1: sintered ore temperature

Fig. 3 Plant characteristics.



Si : cell in the disturbance space
Pi : probability table corresponding to Si
TAC : atmosphere temperature
PR : production rate
REV : revolutions of an induction fan
TA3S: set point of mixed air temperature
TS1,PWR: see Fig.3

Fig. 4 Holon-type hybrid control for a heat recovery plant.



TA5: hot gas temperature
TA3S,TS1,REV,PWR: see Figs. 2-4

Fig. 5 On-line control.

Development in the Future

The proposed holon-type hybrid controls aimed at permitting a sophisticated contro system to be implemented easily without building any model of the process to be controlled. This concept belongs to the concept of model-free control. In recent years, attempts have been actively made to apply knowledge engineering--an AI design procedure --and fuzzy theory to control. However, from the viewpoint of main taining good harmony with modern control theories, the proposed control system is considered effective. Today, new developments revolving around neural networks are being made. This technique permits the teaching signal and judgment signal to be given simultaneously to a neural network to automatically build a required recongnition logic, which has hitherto been built from judgment signals. We intend to units this technique with our control system,since they seem to be very compatible with each oter.

So far, we have descrived the concepts of various types of control. The systems we have to handle are complicated. Dynamic systems may reasonably be divided into lumped parameter systems and distributed parameter systems. However, some systems consisting of multiple distributed parameter systems must be handled as lumped parameter systems. However, we may have created an evaluation function containing incompatible terms and tried to maximize or minimize it.

It is impossible to devise a control system which metts all conditions. We can, however, apply the stochastic control theory to systems having stochastic disturbances; the multivariable control theory to system handling many types of input and output; the adaptive control theory to systems whose process characteristics are unknow or change with the lapse of time; or any combination thereof, on the basis of one or two outstading characteristics of any given system.

In today's world, increasing importance is being placed on humanity. In the field of control, too, logic-based controls(controls based on fuzzy theory or knowledge engineering) are becoming a tool to handle systems which are difficult to express quantitatively.

It is said that the fragility of modern technology lies in:

1) Limits to logical approach
2) Limits to capacity for recognition of the physical world
3) Lack of self-restoring capability

Logical-based control, which utilizes expert knowledge and know-how, seems to be able to us give an effective solution to the first problem in the foreseeable future. What about the second and third problems? Can they be solved merely by employing classical control, modern control, and logic-based control in proper combination? Implementing a distributed, autonomous, cooperative control system, for example, will require intelligence analysis engineering which deals with human psychology, physiology, language, and thinking. In this case, it will be necessary to elaborately combine fragmentary, incomplete theories.

All animal organs have feedback and feedforward control functions, as well as various self-adjusting mechanisms. The existence of such autonomy has been proved by organ transplantations.

At the beginning of this century, Alexis Carrel showed that a fragment of tissue taken from the heart of a chicken before it was hatched had continued to pulsate in a culture solution for years. Since then, it has been made clear that any living organ taken out of its body and properly preserved in a test tube or implanted in another body functions as a quasi-autonomous whole. Thus, even a triflingly small portion of a cell evidently functions as a truly autonomous entity in accordance with its built-in "rules". It seems that this mystery of living things holds the key to the solution of the second and third problems mentioned above.

In any case, what matters is that individual control elements as a whole function effectively. In this respect, it seems necessary to study the means to reinfore sintropy ("inborn drive of a living thing needed to complete its self" as defined by Albert Szent-Györgyi, Nobel Prize-winning biologist). As elementary technologies,fuzzy theory, expert system, parallel processing, neural network, multivalued theory, and many other useful technologies have been developed. In the meantime, the advances in microelectronics have made hardware easier to use. Diversified processes (uncertainly--fuzziness--intrinstic diversity, multifacetedness) are calling for diversification control. In this context, we emphasize the need of holon-type hybrid control.

It is said that those who are engaged in engineering design activity which strongly calls for logical thinking develop only the left side of the brain and invite deterioration of sensibility as the right side gradually withers. When this phenomenon develops markedly, they can becom emotionless and insensible. It is also said that creativity comes from the right side of the brain when it is stimulated by sensibility. Losing sensibility is critical to us engineers. So, we should direct our efforts to adding beauty and flexibility to dry, logical control theories.