MIRROR PLANT On-line Plant Simulator and its Applications

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In recent years, dynamic simulators have been increasingly used throughout the entire plant lifecycle from plant design to operation. Omega Simulation Co., Ltd. (OSC) has developed the OmegaLand integrated dynamic simulation environment, which uses OSC's Visual Modeler plant simulator as the core simulation engine. Plant models developed by this plant simulator can reproduce behavior of actual plants, and the simulator can therefore be applied not only to operator training but also to the renovation of plants, validation of control logic, and other purposes. OSC has also developed MIRROR PLANT, an on-line operator supporting system that uses tracking and dynamic data reconciliation technologies. MIRROR PLANT is being applied to an actual plant in order to evaluate its operation supporting applications.

INTRODUCTION

Omega Simulation Co., Ltd. (OSC) has developed the OmegaLand integrated dynamic simulation environment which reproduces behaviors resembling actual plant operations and provides for a realistic feeling. Although dynamic simulation has been used mainly for operator training systems (OTS), it is recently being used off-line as a substitute for actual processes when verifying control algorithms, process improvement, process optimization, and so forth. However, from the viewpoint of direct assistance to operators, off-line use of dynamic simulation has had a drawback in that it could not instantly follow fluctuations in processes such as changes in operational conditions.

Meanwhile, there are on-line operational assistance technologies which use steady-state models such as real-time optimizers. However, in processes with values constantly fluctuating, such as liquid levels, values calculated by steady-state models always deviate from the actual values. Therefore, this model is not satisfactory for an operator's operational assistance function for continuous monitoring.

There is another technology what is called a soft sensor for estimating the internal status of process equipment. This technology estimates values of unobserved state quantities at a given time from observed values at that time, regardless of the phenomenal dependency among those values. Therefore, in principle, soft sensors cannot respond to fluctuations in conditions such as loads and raw material compositions nor can they be applied to the prediction of future statuses such as performance shifts in the processes, and thus they cannot provide conditions for optimization or operating limits.

To solve these problems, OSC has developed MIRROR PLANT, an on-line simulator for operational assistance to operators which uses OSC's Visual Modeler chemical engineering based simulator as a simulation engine [(1)]. MIRROR PLANT combines the tracking technology and data reconciliation technology with dynamic compensation by the least-squares method to fit models to the actually measured data in an on-line and real-time basis.

Figure 1 shows the MIRROR PLANT schema. MIRROR PLANT is composed of the following three components:

1) The mirror model which receives on-line data from the DCS, a part of the actual plant, and performs real-time simulation to create a mirror image of the actual plant. It also estimates and visualizes state quantities which are not measured.
2) The identification model, which periodically estimates performance parameters of the equipment, to fit the models to the actually measured values.
3) The analysis model which achieves various operational assistance functions.

First, this paper introduces the operational assistance functions of MIRROR PLANT. Then, it describes details of the tracking and data reconciliation with the dynamic compensation, which are the base technologies of MIRROR

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PLANT. After that, a targeted plant and range of modeling for MIRROR PLANT application are introduced. In the last two sections, actual application examples of the tracking and data reconciliation with dynamic compensation are described and summarized.

OPERATIONAL ASSISTANCE FUNCTIONS OF MIRROR PLANT

The operational assistance functions of MIRROR PLANT are described below. These functions have been completed through the prototype development and field verification operations in an actual plant. The main features are summarized in this paper. Details are described in the reference [2].

1) Visualization of the inside of a plant
   State quantities at locations where sensors are not installed are estimated.
2) Estimation and monitoring of performance parameters
   Performance parameters such as catalytic activity and the heat-transfer coefficients of heat exchangers are estimated, and the performance or status of equipment can be monitored.
3) Steady state prediction
   For example, a steady-state balance can be predicted from the current plant status when operational conditions such as production volumes are changed. One of the applications is to find and provide the optimal operational conditions.
4) Transient state prediction
   Future dynamic behaviors of a plant can be predicted from the current plant status, assuming that current operational conditions are maintained. Applications of this function include examining and providing operational procedures for avoiding critical operating conditions, and investigating for improving control performance.

Figure 2 shows an example of screens. Like a DCS, MIRROR PLANT can display the calculated values of a model on a process flow. On the sub window, it displays state quantities such as a temperature, flow rate, or composition in certain piping. Various functions such as steady-state prediction can be started from the menu on the left side of the main screen.

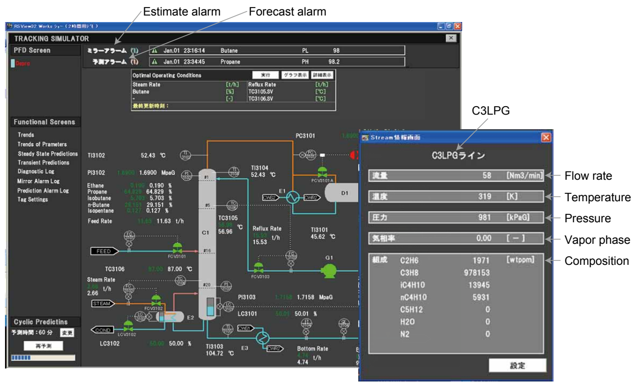

Figure 2 An example of an operational assistance screen of MIRROR PLANT

TRACKING AND DATA RECONCILIATION WITH DYNAMIC COMPENSATION

Figure 3 shows the MIRROR PLANT operational sequence, especially the execution flow of the mirror model and the data reconciliation with dynamic compensation.

The mirror model performs dynamic simulation while executing processing for fitting the model to the actual plant at every calculation interval. This processing is called tracking. This tracking aims for local conformity, and is achieved by the following four means:

1) Measurement values such as temperature or pressure at the boundary of the model are taken into the mirror model.
2) The control parameters of the controllers in the DCS, including set values (SV), PID parameters and alarm high/low limit values are taken in as control parameters of the controllers in the mirror model.
3) If a control action, e.g. level control, in the mirror model is slow and this affects other parameters such as that of pressure or temperature, the process variable (PV) of the actual plant is taken in as an SV of the controller in the mirror model. Furthermore, its manipulation variable (MV) is provided to the model as a feed-forward signal to enhance responsiveness.
4) In the case where it is important for a state quantity in the model to coincide with that in the actual plant even

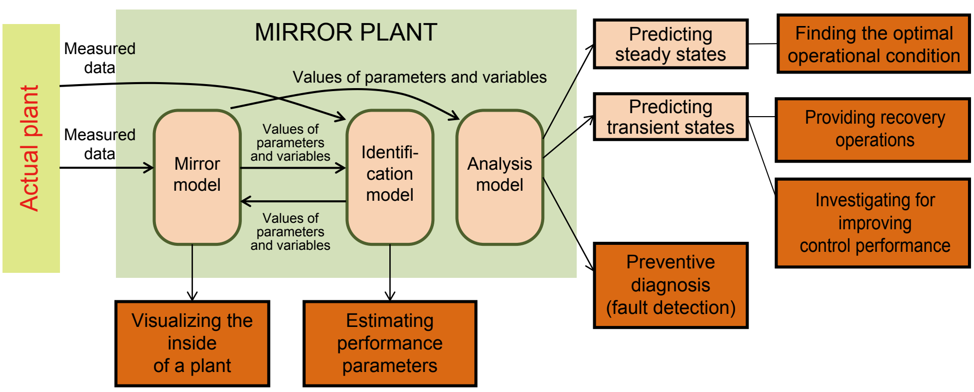

Figure 1 Configuration of MIRROR PLANT

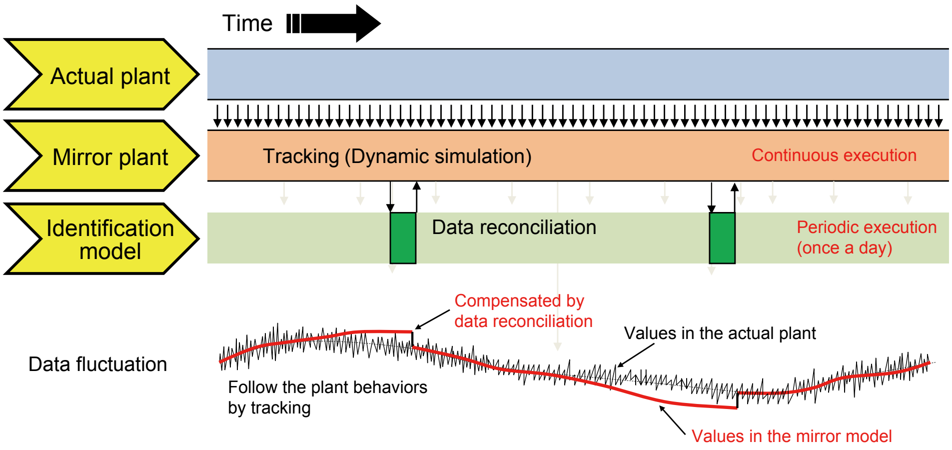

Figure 3 Operation sequence of MIRROR PLANT

though it is not controlled in the actual plant, if the relation between the state quantity and the equipment parameter is locally restricted, an equipment parameter in the mirror model is adjusted so that the value calculated in the mirror model agrees with the measured value at the actual plant. For example, if a temperature at the outlet of a heat exchanger is an important state quantity, the heat transfer coefficient of the heat exchanger in the mirror model is automatically adjusted so that the temperature in the mirror model agrees with the measured value at the actual plant.

On the other hand, although the data reconciliation in the identification model also aims to fit the model to the actual plant, it deals with relatively slow changes, such as catalyst degradation or fouling, which are detected by multiple sensors in a wide area. Therefore, the data reconciliation can also be executed at a relatively long interval, for example, once a day.

Previously, data reconciliation assumed that the process is in a steady state. In fact, it is difficult to assume the process to be in a steady state at all times, and thus the execution timing was limited. Meanwhile, MIRROR PLANT performs the tracking to trace the actual plant behaviors in real time as described above, and simultaneously calculates the variation in holdup. OSC has developed a method for data reconciliation with dynamic compensation, a data reconciliation calculation method which takes this holdup variation into account, in addition to constraints of the mass balance and heat balance of the identification model, and minimizes the residual sum of squares between the estimated and the observed values. This method takes errors caused by dynamic variations into account, and achieves more precise data reconciliation.

Figure 4 shows a simple tank system. With reference to this figure, the data reconciliation with dynamic compensation is explained below. When the input flow rate is f_i, the output flow rate is f_p, and the holdup volume in the tank is U, the mass balance of the tank is expressed by equation (1).

$$\frac{dU}{dt} = f_i - f_p \quad \cdots (1)$$

In the non-steady state, dU/dt in equation (1) is not 0, and thus $f_i \neq f_p$.

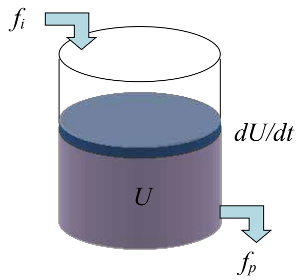

Figure 4 A tank system

When the estimated value is f, the observed value is f^*, and their residual sum of squares is E, the following equation holds.

$$E = (f_i - f_i^*)^2 + (f_p - f_p^*)^2 \quad \cdots (2)$$

The data reconciliation is achieved by finding f_i and f_p that minimize E under the constraint condition below derived from the mass balance equation.

$$f_i = f_p + \frac{dU}{dt} \quad \cdots (3)$$

The existing data reconciliation technology assumes that the process is in a steady-state, in other words, dU/dt of equation (3) is 0. This was achieved by judging the state before executing the data reconciliation or by preprocessing with a moving average filter or other means. However, the actual plants cannot be in the steady state in a precise sense, and moving averages are not always equivalent to steady-state values when operation conditions fluctuate, and so these cause estimation errors. In contrast, MIRROR PLANT quantifies the dU/dt constantly during the tracking and uses this value in the constraint equation for data reconciliation calculation, enabling a more precise compensation for the dynamic unbalance. This is called dynamic compensation. To simplify the explanation, only the mass balance is considered. The mirror model, which uses an exact chemical engineering model, can compensate for dynamic unbalances in heat and composition balances as well.

TARGETED PLANT AND RANGE OF MODELING

The plant where the MIRROR PLANT field verification operations were performed includes reaction, recovery and refining processes. Its process structures are similar to the basic structure of a general chemical process shown in Figure 5.

The modeling has been carried out for the entire system except for the areas which are not used in normal operation, such as the areas peculiar to the start-up.

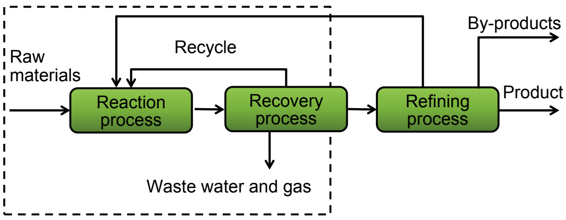

Figure 5 Basic structure of a chemical process

APPLICATION EXAMPLES OF THE TRACKING AND THE DATA RECONCILIATION WITH DYNAMIC COMPENSATION

Tracking

Following the four means described earlier, the data from a DCS of an actual plant are input into the mirror model through the OLE for process control (OPC) interface. Logics necessary for switching control modes such as MAN or AUTO and switching over to back-up equipment are also implemented.

Application Range of the Data Reconciliation with Dynamic Compensation

In the targeted plant, catalysts in reactors degrade depending on the processed volumes and have to be replaced once every few years. Because the degree of degradation depends on the processed volumes, it is difficult to model and forecast it precisely. However, because the degree of degradation usually does not change rapidly in a short time, it can be estimated by the data reconciliation with dynamic compensation.

Although MIRROR PLANT covers the entire process, from reaction to production, the application range of the data reconciliation with dynamic compensation can be limited to the range in which the parameters of concern have an effect. Limiting the range has the advantages of faster calculation and better convergent calculation. Because the purpose is to estimate catalyst degradation, the application range was limited to a part of the reaction and recovery process, and the recycling process of unreacted gases.

The rectangle of dashed lines in Figure 5 shows the scope of the identification model. First, raw materials are fed into the reactor. After the reaction to produce product reactant in the reaction process, unreacted materials are collected in the recovery process, and by-products or impurities are removed in the refining process which produces the final products. Unreacted materials are recycled to the reactor again. Inert components which are not involved in the reaction accumulate in the processes, and so they are purged through waste water or waste gas piping. At the same time, reaction heat is recovered in the reaction process. The independent variables and evaluation variables for the data reconciliation in this field verification operation were defined as shown in Table 1. The execution frequency was decided to be once a day, based on a preliminary study.

Table 1 Independent variables and evaluation variables for data reconciliation

Independent variables	Reaction rate Measurement error in feed flow rate Measurement error in composition
Evaluation variables	Composition measured value Feed flow rate Flow rate in the process Amount of recovered reaction heat

The MIRROR PLANT implementing the mechanisms described above is connected to an actual plant and is running on-line.

CONCLUSION

OSC has developed a method to accurately reproduce behaviors of an actual plant on a computer by using OSC's Visual Modeler dynamic simulator as a core simulation engine. This method combines tracking technology based on local relations and data reconciliation technology with dynamic compensation, which make use of wide range and redundant relations.

MIRROR PLANT is running in an actual plant for field verification operations. OSC will further improve various operation assistance functions on the basis of feedback from the operators.

REFERENCES

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