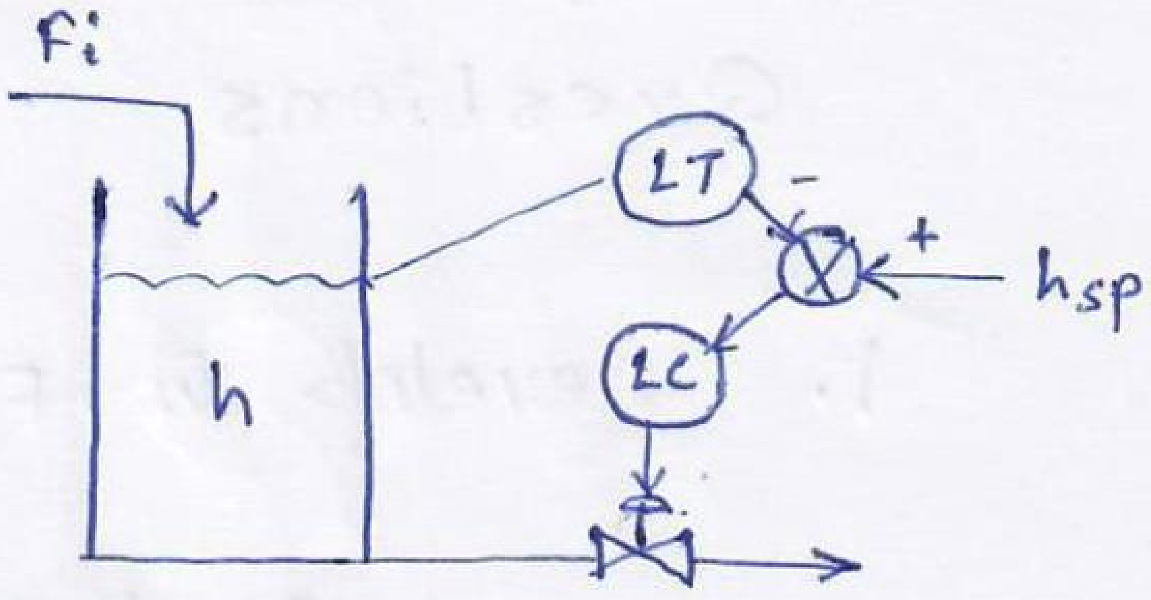
## Hardware of a control system




1. The process : physical and chemical operations occur.

2. Measuring sensor : Used to measure
   - LV --- FF controller
   - CV --- FB controller
   - Secondary meast -- Inferential controller

| Variable | Sensor |
|---|---|
| Temp | Thermocouple , RTD |
| Pre. | Manometer |
| Flow | venturimeter, orifice meter |
| Liq level | DP cell |
| comp | chromatographic analyzer (GC) |

3.

3. Transducers

Measurement → Transducer → physical quantity

T, P, C

(cannot be used for control)

(voltage, current pneumatic signal)

@ transmitted easily

4. Transmission line

- Used to carry measurement signal from sensor to controller

electrical signal

- This signal may be very weak (few millivolts) and cannot be transmitted over a long distance

@ In such a case, the transmission line is equipped with amplifier.

5. The controller

- Receives measurement information from sensor

- Decides what action should be taken

6. Final control element (FCE)

- Control action is implemented through FCE
- Examples : control valve, variable speed pump & compressor, switch

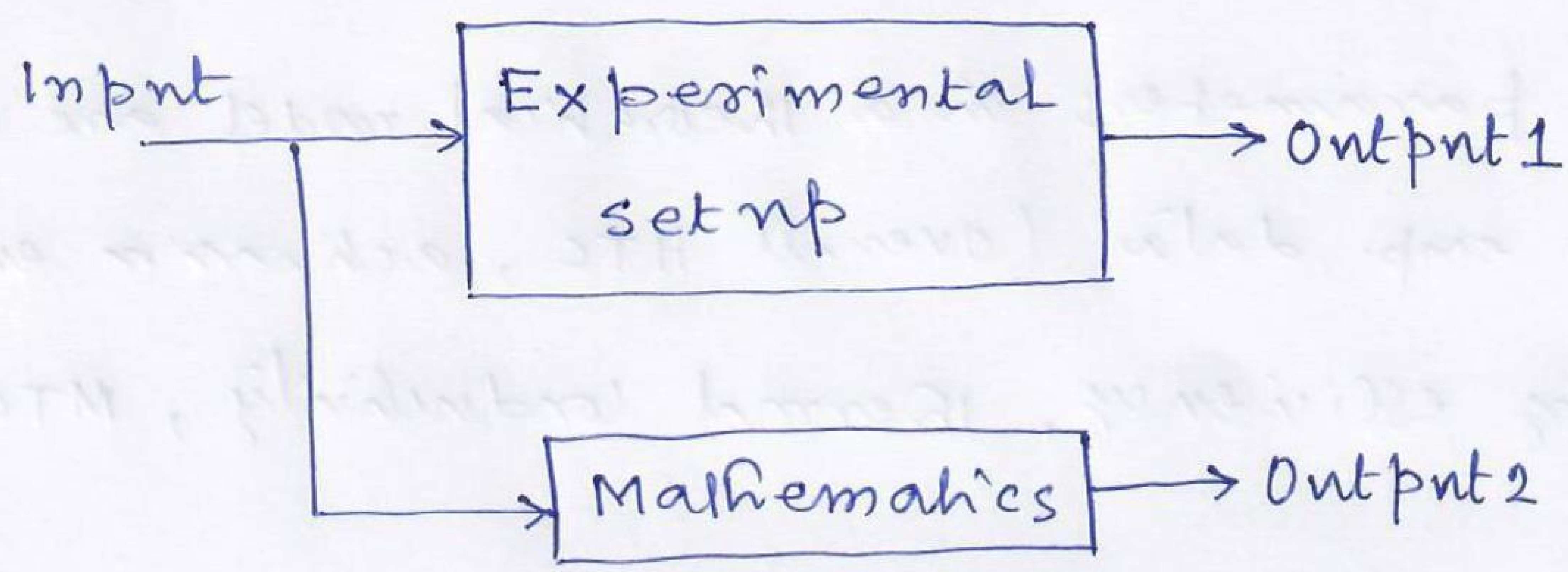
7. Relording device

- Used to visualize and record the plant behavior through measurement signals.
- Video display unit (VDU) is accomodated in the control room to serve this purpose.

Direct digital control (DDC)

- Directly receives the measurements from the process
- Calculates control action (MV) based on the control law programmed in the computer
- control action is implemented directly by the computer through the FCE.
- This direct implementation of the control decisions gave rise to the name "direct digital control".
- This is widely used in industrial applications.

# Mathematical Modeling




- For a good model, both the outputs should be close enough

Model is the mathematical representation of a process intended to promote understanding of the real system.

The solution of the model equations (usually made by using a computer) - simulation

## Types of Models

classified based on how they are obtained

1. Theoretical model - developed based on conservation principle
2. Empirical model - obtained by fitting exp. data

   e.g. least-squares, ANN

   Enthalpy $H = a + bT + cT^2$ ; Dittus-Boelter eqn

3. semi-empirical / hybrid model – combination of the above two.

Ex – Few parameters in a theoretical model are calculated from exp. data (overall HTC, activation energy, tray efficiency, thermal conductivity, MTC, $\lambda$)

Theoretical model

Advantages

- It provides physical insight into process behavior
- Applicable over a wide range of conditions

Disadvantages

- It leads to be time-consuming to develop
- some model parameters (e.g., HTC, MTC, $\lambda$) are not readily available

Empirical model

Advantage

- It is easier to develop

## Empirical model (contd..)

### Disadvantages

- It does not extrapolate well
- Thus it is applicable to a limited range of conditions
- No physical insights

### Distillation tray temp (T)

- Empirical model finds T without having information on m & x
- Theoretical model finds T with having m and x

m ← tray holdup; x ← liq comp.

physical insight

### Need of simulated model

1. Improve understanding of the process
2. Train plant operating personnel
3. Selection of control pairings & tuning
4. Development of model-based controller
5. Optimize process operating conditions
   - Process model and economic information can be used to find the most profitable op. conditions

# State variables and state equations

## State variable

- It describes the natural state of a given system
- Through the three fundamental quantities:
  mass, energy & momentum
- These quantities cannot be measured directly and conveniently

  e.g. mass of liq in a tank at dynamic state = $Ah\rho$

- Measured variables (e.g., T, P, $\rho$, C) are grouped to determine the value of fundamental variables
- These characterizing variables are called state variables.

  T, P, C

## State equation

The equation, which is derived by the application of the conservation principle on the fundamental quantities to relate the state variables with the other variables (including other state variables), is called state equation.

## Conservation Law

$$\begin{pmatrix}\text{Rate of}\\ \text{accumulation}\end{pmatrix} = \begin{pmatrix}\text{Rate of}\\ \text{input}\end{pmatrix} - \begin{pmatrix}\text{Rate of}\\ \text{output}\end{pmatrix} + \begin{pmatrix}\text{Rate of}\\ \text{generation}\end{pmatrix} - \begin{pmatrix}\text{Rate of}\\ \text{depletion}\end{pmatrix}$$

- Total mass cannot be generated or depleted; so there is no generation or depletion term

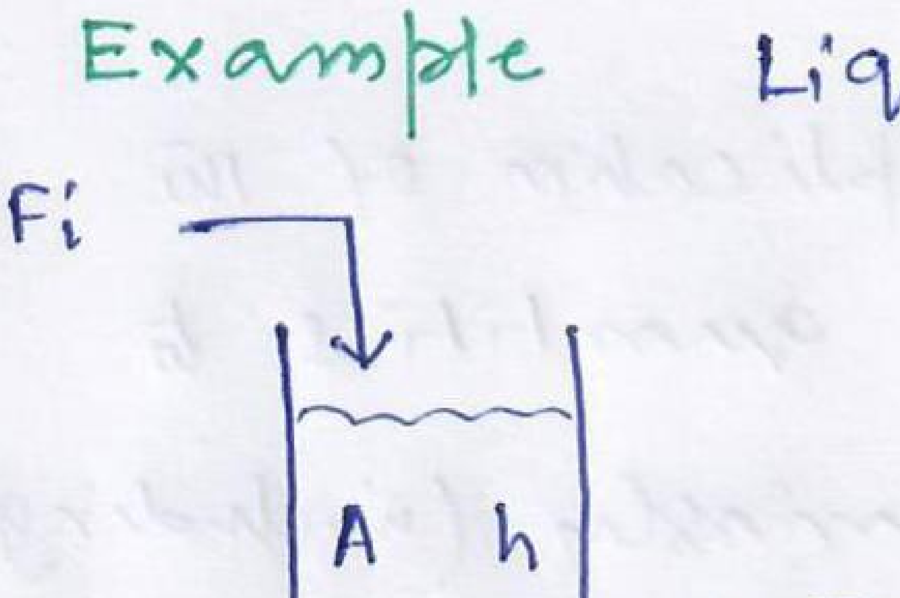
- Comp i balance

$$\begin{matrix}\text{Rate of comp } i\\ \text{accumulation}\end{matrix} = \begin{matrix}\text{Rate of comp } i\\ \text{in}\end{matrix} - \begin{matrix}\text{Rate of } i\\ \text{out}\end{matrix} + \begin{matrix}\text{Rate of } i\\ \text{generated}\end{matrix}$$

- Energy balance    First-law of thermodynamics.

$$\begin{matrix}\text{Rate of energy}\\ \text{accumulation}\end{matrix} = \begin{matrix}\text{Rate of}\\ \text{energy in}\end{matrix} - \begin{matrix}\text{Rate of}\\ \text{energy out}\end{matrix} + \begin{matrix}\text{Rate of energy}\\ \text{generation}\end{matrix}$$

Example    Liquid tank




Mass bal: $\dfrac{d(Ah\rho)}{dt} = F_i\rho - F_o\rho$

$A\dfrac{dh}{dt} = F_i - F_o$ --- state eqn.

$h \rightarrow$ liquid height --- state variable

$F \rightarrow$ volumetric flow rate

$\rho \rightarrow$ liq density