1. System Response Methods
   1. Impulse Response
      1. Impulse Response Model Representation

* Unit Impulse function

* Convolution Model (Impulse response model)
* If is known, then is easily computed given
  + 1. Transfer Function Model Representation
* Laplace transform
* The transfer function
* Ex.2.1: Recall the liquid storage tank
* The transfer function
  + 1. Direct Impulse Response Identification
* Identification of given in Discrete Convolution Model

1. Discrete convolution model

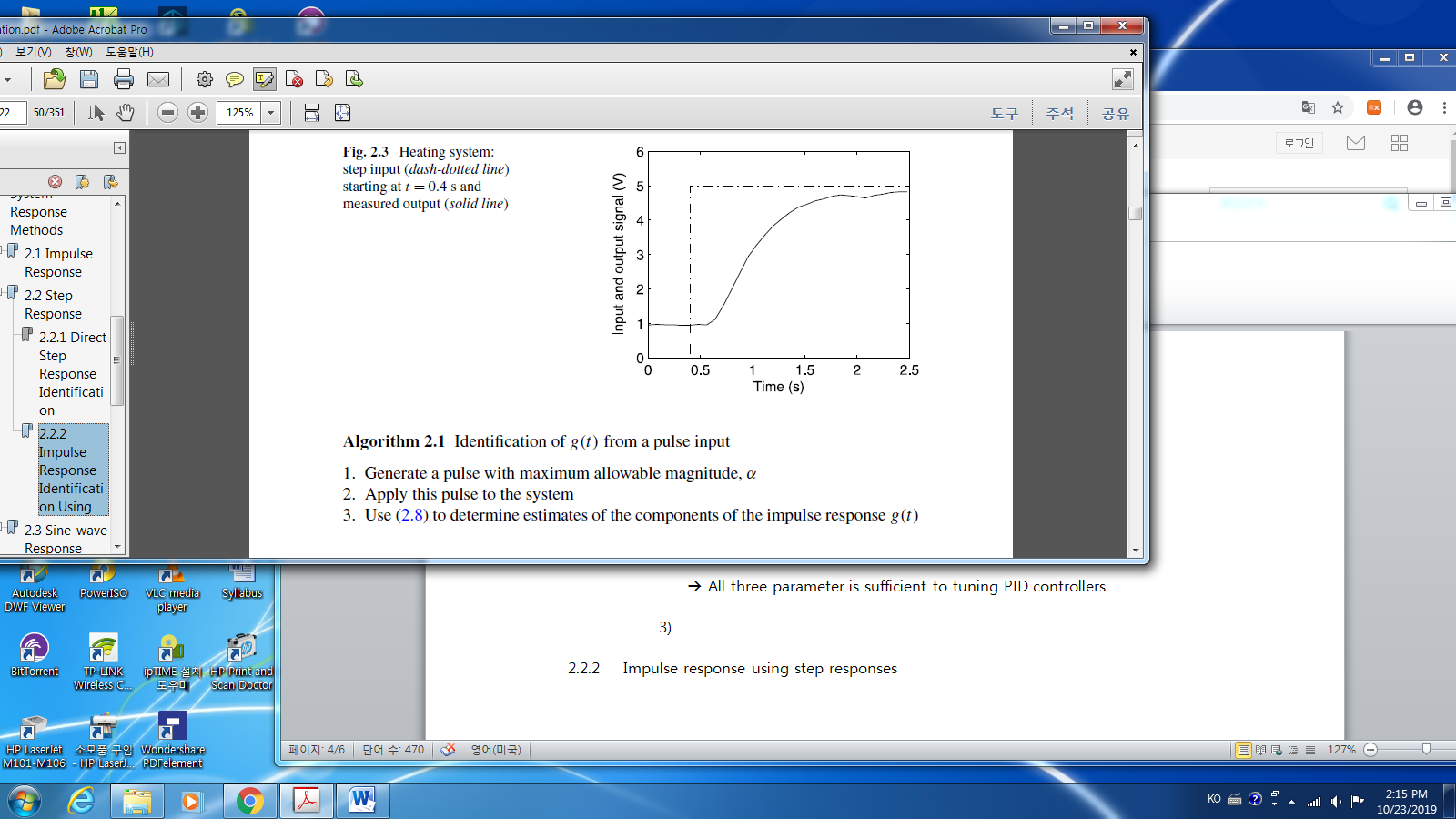
Therefore

1. Case of Pulse Input

In general, let input as

Then the output is

* 1. Step response
     1. Direct Step Response
* Dead time : 0.2sec
* Time constant
* Static gain : ~ ~ (4.8-1)/(5-0)= 0.76
* 🡪 All three parameter is sufficient to tuning PID controllers



* + 1. Impulse Response Identification Using Step response
* How to get :
  1. Sine-Wave Response
     1. Frequency Transfer Function
* Continuous Frequency Response
* A sampled system: **Discrete Fourier Transform of**
* Remember:

Since

And a system is causal,

* + 1. Sine wave response Identification
* Input

Output from (2.5) with

* Ex. 2.5

-.

-. Gain: ~ Phase delay =

* Continuous / Discrete Fourier Transform

Laplace transform, z-transform

1. Frequency Response Method
   1. Empirical Transfer-function Identification
      1. Sine wave testing

* In order to get “Bode-plot”, we need infinite
  + 1. Discrete Fourier Transform of Signals
* **The Discrete Fourier Transform(DFT)**

-. sampled at

where

-. For

Hence for a is the period of

* Question: what is the maximum frequency of (3.1)?
* Ex.3.1 Sine-wave signal

-. Given

where and

-. Find when

Hence

For simplification, using the following relationship:

so that

* Periodogram: the plot of values of
  + 1. Empirical Transfer Function Estimate
* Empirical Transfer Function Estimate(ETFE) for Samples systems
* For LTI

Now for a sampled system, , the estimate of is

* The empirical transfer function estimator
* Ex. 3.2 : Empirical Transfer Function Estimator : matlab test…
  + 1. Critical point identification:
* In a system with a relay, which is not a linear component, hence the system is a non-linear system.
* Sometimes stable limit cycle oscillations
* What is the limit cycle? 🡪 we should learn in non-linear (control) system.
* Skip and later study
  1. Discrete-time Transfer Function
     1. z-transform
* Discrete Fourier transfer function of a sampled system
* z-transform
* as a Laplace transform goes to 0 to ,
* transfer function in domain

Then the z-transform of



* + 1. Impulse response identification using Input-output data

For t=0



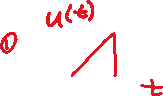
In matrix form

* Shift operator
  + 1. Discrete-time Delta operator

1. Correlation Method
   1. Correlation Functions
      1. Autocorrelation Function

* Time average of Autocorrelation Function

-time average in time -invariant system



Discrete-time case



* Properties of auto correlations



1. If u(t) is periodic, then is periodic
   * 1. White Noise Sequence



* Definition of white noise



* + 1. Cross-correlation Function

As time average

In discrete case



* 1. Wiener-Hopf Relationship
     1. Wiener-Hopf Equation
* The in/out cross correlation

Hence

* + 1. Impulse Response Identification Using Wiener-Hopf Equation
* Exm. 4.3: **Impulse response identification**

For asymptotically stable systems, it suffices to determine only **the first elements of ,** so that

* Inputs, and output: , and .After removal of the initial conditions effect, , and
* In/out correlation matrix
* Remember



* + 1. Random Binary Sequences
* Motivation: If the input is selected as

Then is a diagonal matrix, which is simple to get as

The problem is how to select a signal as (4.2.3.a)

* white noise

See (4.6). But not realizable since

- vary large input

- not genuine random noise.

* Random Binary Sequence(RBS)
  + 1. Filter properties of Wiener-Hopf Relationship
* Why Correlation method rather than impulse response identification?

1. (3.2.2.a) we may get .
2. Due to measurement noise, the output is corrupted by the noise.
3. To cancel the noise, (3.2.2.a) may not be possible.
4. The correlation method may filter the output measurement. See the following.

Then

If is uncorrelated, , then

* Correlation method(Wiener-Hopf Relation) will filter out the measurement noise.
  1. Frequency Analysis Using Correlation Techniques
     1. Cross-correlation Between Input-output Sine Waves
* Motivation

If the output is corrupted by noise, the previous EFTE may not be good to filter the noise.

We need to filter out the noise.

1. Let the input / output be

Multiply the output by the and , denote the result as

where sample time, N : # of sampling

1. Sin term

If and has no component of the input frequency,

1. Cos term
   * 1. Transfer-function Estimate Using Correlation Techniques

From the previous calculations, the estimate of is