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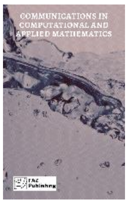

Development of Modelling of Couple Tank System CE 105 Using ARX Method

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Abstract: Liquid level control is a process control in tank systems and widely used in industries processes application. A CE105 coupled tank apparatus consists of two liquid tanks, where the tank is used to accept incoming liquid while keeping the liquid variation at the desired output level to supply outflow of liquid at a constant speed. Each tank has a scale level that proportional to the signals level sensor and it has a variable speed pump forces liquid into the first tank. This research proposed a development of ARX model for coupled tank system. The Nonlinear Autoregressive with Exogenous (ARX) model structure was chosen to represent the system dynamics for simulation studies. The nonlinear ARX model was successful to describe the behaviour and dynamic of the system. Simulation with the model has been successfully modelled.

Keywords: Liquid level, CE 105, Nonlinear Autoregressive with Exogenous (ARX)

1. Introduction

Control of liquid level is a typical representation of process control in tank systems and widely used in industries processes such as petroleum, chemical, water treatment and other industries [5, 6]. In any control system, the designing of the control system is the most important thing. There are different types of controllers, which can be conventional or intelligent. A controller measure and control the flow of water through a motor pump to maintain a level set point at a given value and the controller be able to accept a new set point [5]. One of the most and simplest commonly used industrial tank systems is coupled tank system. A couple tank systems consist of two liquid tanks, where the first tank is used to accept incoming liquid while keeping the liquid variation at a desired an output to supply the liquid at a constant speed.

The CE105 coupled tank system which is available in Control Laboratory, FKEE, UTHM used as a model to represent the system dynamics for simulation studies by using the ARX structure System Identification. The project is based on designing the model based on a computer software system to represent control liquid level in a CE105 coupled tank system.

A suitable mathematical model of the system is needed in order to design a good controller to achieve an accurate set point. The mathematical modelling for an unknown system which has unknown parameters can be obtained. However, not all mathematical model that can reflect a real plant's behavior. System Identification (SI) technique is the process of modelling the dynamic system from the experimental data. SI technique provides an efficient approach and proved to be very significant in practical applications.

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1.1 System Description of Coupled Tanks System

Model for plant system in this project is CE105 Coupled Tanks Apparatus. The plant system is manufactured by TQ Education and Training Ltd, 2001 [1, 8] and the image of the coupled tanks system as shown in Figure 1. This system comprises two separate vertical tanks, which are connected by a flow channel [1, 2]. This system has a sensor and transducers which are two pressure sensing liquid level and flow transducer in range of 0 to 10 VDC. The schematic and specification of coupled tanks system as shown in Figure 2 and Table 1.

Figure 1: Image of CE105 Coupled Tanks System Apparatus

The CE105 capability to shows fluid transport and liquid level control problems in process control. The basic control problem is to regulate the liquid level in one of the tanks by varying the speed of the circulating pump [8].

Table 1: Specification of CE105 Coupled Tanks System

Tank 1	Cross Sectional Area = 9350 mm^2
Tank 2	Cross Sectional Area = 9350 mm^2
Valve A, B, C	10mm Valve Orifice Cross Sectional Area = 78.5 mm^2
Liquid Level Sensors	0 to 10 VDC Output Corresponding to 0 to 250 mm As indicated on the front panel water level scales
Pump Flow Sensors	0 to 10 VDC Output Corresponding to 0 to 4400 mm As indicated on the front panel flow meter
Variable Speed Electrical Pump	0 to 10 VDC Input

The schematic diagram detail of component in CE105 is shown in Figure 3.3. The system has three rotary valves which are Valve A, B and C. The system enables to flow variation condition of the entire system by adjusting the condition of Valve A, B and C. Valve B and C flow out liquid direct into the reservoir below from the left and right hand tanks respectively. Function for Valve A is used to vary the coupling between the two tanks. In all cases, the scales adjacent to each valve indicate the relative discharge rate: from 0 to 5 (closed-open) [5].

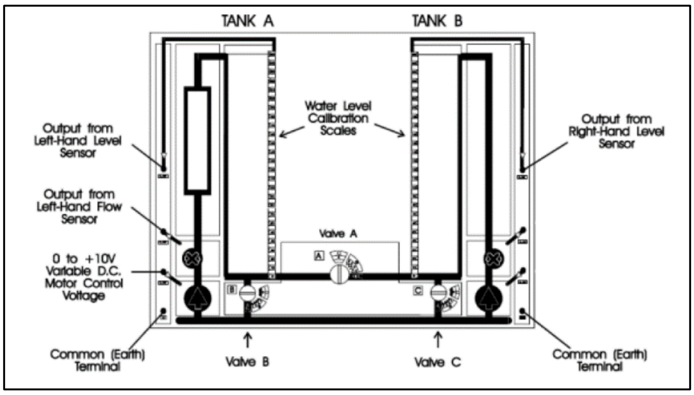


Figure 1: Schematic diagram of component in CE105

An overflow channel is included at the top of each tank. Pressure liquid level sensor is located at each tank that produces the voltage to 0 to 10 VDC. The output from the pump is sensed by an in-line flow transducer of the variable reluctance type.

The top unit of the CE105 contains the mains supply unit connector and the AC to DC rectification circuit. These are mounted in a sealed die-cast box designed to prevent water from entering. This ensures that the user isolated from potentially dangerous voltage levels.

The motor drive and transducer signal conditioning circuit (flow and level) are also located in the top unit of the CE105. Electrical connections between the individual transducers, the pump drive circuit and the top unit are made with the relevant plugs and sockets being correctly fitted at the time of installation.

The inlet channel is connected with the variable speed electrical pump which works with different voltages in the range from 0 to 10V. The level sensor gives output signals proportional to the water level in each tank [1, 8]. The manipulated input can be set manually from simulation on a personal computer (PC) [5].

1.2 Modelling Coupled Tanks System

In many industries processes such as petrochemical [2, 5], paper making [5], chemical process [26, 21], food process [21] and water treatment [5] require control liquid level in a tank system. The liquid in process should be pumped, stored in tanks, and then pumped to another tank [2, 5]. Often the tanks are so coupled together that the levels interact and this must also be controlled [2].

In the process control, it is necessary to build some model to represent the system in order to anticipate the process output without the real process taking place. From the plant mathematical model, the process behaviour and dynamic can be observed. In designing and analysing control system, assumption of a dynamic plant model in the standard state space is realized. Mathematical models of a physical system can be derived from the knowledge experienced from the underlying mechanism of the system where the variable of the system will be represented by mathematical relationships [3].

System identification is process developing or improving the mathematical representation of a physical system using experimental data. System identification was a system that usually was used in a control system. Especially for modelling transfer function for any plant system. This system was wellknown as an art and science of building a mathematical model of a dynamic system from observed input output data [24]. The approaches that can be used for modelling proposed to coupled tanks system such as black box [25, 26].

In performing black box modelling, many model structures are being revised to offer an efficient way to modelling the system [3]. There are many researchers reported that applied black box technique in performing system identification for coupled tank system. From the authors H.Bastida et al [2] had applied the identification system model using Bode diagrams. Bode diagrams are the representations of magnitude and phase versus frequency of a sinusoidal transfer function, it is the representation of a system transfer function for sinusoidal inputs at different frequencies.

Next, M. Shahrieel et al [24] had applied system identification of transfer function to developing the mathematical representation of a physical system of water system using experimental data. The experimental results showed the entire model was achieved over than 80% which it can conclude that the modelling was achieved but the step test results showed overshoot on the PID controller. Avoid hyphenation at the end of a line. Symbols denoting vectors and matrices should be indicated in bold type. Scalar variable names should normally be expressed using italics. Weights and measures should be expressed in SI units. All non-standard abbreviations or symbols must be defined when first mentioned, or a glossary provided.

1.3 Experiment and Data Collection

During the experiment, the input output data that represents the system under consideration through real time or simulated using a computer was collected. There are several issues that are to be focused on such as the input signal, sampling period and data pre-processing [3].

The input signal was applied to the system in order to pseudo random binary sequence (PRBS) are probably the most convenient inputs for linear system identification. PRBS provides the best and useful approximations to periodic white noise. It is the forcing functions most widely used in statistical system testing. [26]. Most system identification works apply PRBS [3, 18, 20, 26] as an input signal and another input signal is step function [4, 24], sine wave [2] and others. PRBS signal input is chosen in the modelling input signal because of its advantages and most practical industrial process [3].

Sampling period setting needed to be a concern in system identification. From the previous study, several guidelines have been proposed by authors based on the system characteristics such as manual three rotary valve setting based on application. From the reviews, the valve configuration is; Valve A=5, Valve B=1 and Valve C=1.5. So based on that configuration the behavior of the system is very slow than the frequencies applied are lower than 0.1Hz [2].

2. Methodology

The focus of this chapter is to provide further details of hardware and software to pursue this project. To ensure the flow of the project run smoothly, three major steps need to be aimed such as planning, implementing and analysing.

The main objective of this project is to obtain the mathematical model of CE105 Couple Tank System. CE105 is manufactured by TQ Education and Training Ltd, 2001 which is available in Control Laboratory, FKEE, UTHM. CE105 used to model and implement the PID controller. The experimental data process plant such as input and output data were taken, data acquisition card, system identification and the software which is MATLAB will be discussed for its implementation.

2.1 Plant Setup

The plant setup will cover the CE105 Coupled Tanks System and data acquisition device. The development of water level control will be divided into two stages, which are the input water flow and output water level sensor. Meanwhile, the input voltage analog and output voltage analog instrumentation covers the sensing system, software development and system interfacing.

2.2 Data Acquisition Device

Data acquisition (DAQ) is the process of measuring electrical or physical conditions such as voltage, current, temperature, pressure or sound with a computer. NI cDAQ-9178, NI 9263 and NI 9201 were DAQ device used in this project. NI cDAQ-9178 is NI CompactDAQ Eight-Slot USB Chassis designed for the small, portable sensor measurement system. Driver installer required for connection with the computer.

The NI cDAQ 9178, NI 9263 and NI 9201 will be as an interface between the coupled tank system and the MATLAB software on the computer [1, 5]. NI 9263 and NI 9201 are analog output and an analog input module for measurement, control and communication application. This module can connect to any sensor and allow high accuracy measurement data acquisition and control applications. Figure 3 shown NI 9263 and NI 9201 on NI cDAQ-9178 applied during the experiment test.

Figure 3: Data Acquisition device

2.3 Experimental Setup

The purpose for experiment setup is to collect and gather datasets on the input and output voltage of open loop test on CE105 coupled tanks system, Data Acquisition hardware and personal computer. The illustration connection as shown in Figure 4, required to troubleshoot the hardware connection and software driver to make sure in working condition. The CE105 voltage range of water pump, liquid pressure sensor and flow rate sensor are 0 to 10V. The NI 9263 and NI 9201 device are used to convert analog to digital signal to and from the CE105. NI cDAQ 9178 be the interface connection between both analog input and analog output device and CE105.

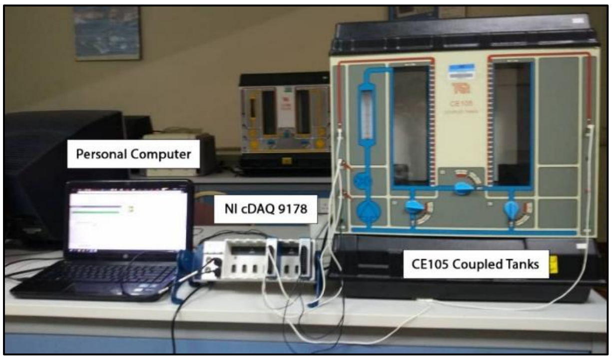


Figure 4: CE105 personal computer and data acquisition hardware

2.4 Block Diagram Implementation

For the experiment implementation, the input voltage range 0 to 10V is supply to the pump through the analog output device NI 9263. The input signal drives the pump which pushes water flow in the range corresponds with the input signal. This system usually required an operator to controls the speed of movement of the output by varying the input. For the liquid level sensor, the range of voltage corresponding is 0 to 10V as an output signal through analog input device NI9201. The input and output signal will send and receive the information to MATLAB than record in workspace file to implement to the next step.

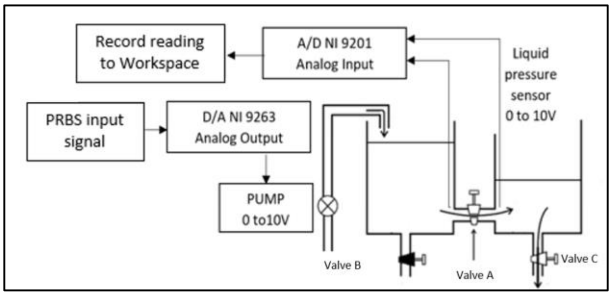


Figure 5: Block diagram for open loop experiment

Figure 5 is the block diagram of an open loop control to determine the system dynamic characteristic of the plant than record the data to the workspace. The input voltage supply adjusted from 0 to 10V to pump and changes of the liquid level tank 1 and tank 2 recorded respect to times.

2.5 Hardware Connection

Input and output voltage on the CE105 coupled tanks system used to integrate between the plant system and computer as shown in Figure 6. Analog Input 0 (AI 0) connected to the water level sensor at tank 1 and Analog Input 1 (AI 1) connected to the water level sensor at tank 2. It also came with the pump connection which is connected to Analog Output 0 (AO 0). Finally, ground both analog devices to the ground pin at CE105.

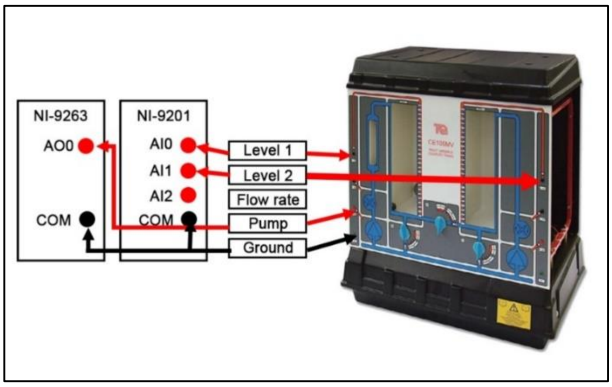


Figure 6: Hardware connection between DAQ device and coupled tanks system

2.6 Interfacing the Level Sensor

After connecting the hardware properly as shown in Figure 7, the input and output analog DAQ has been set up using MATLAB Simulink Data Acquisition Toolbox. As shown in Figure 3.6, the Analog Input block is used to record the liquid level feedback from both tanks. The Analog Output block used to supply input signal in the fixed range from 0 to 10 volts that match with an operating voltage range of CE105 coupled tank system. The sampling rate was set up 10 samples per second for both analog block.

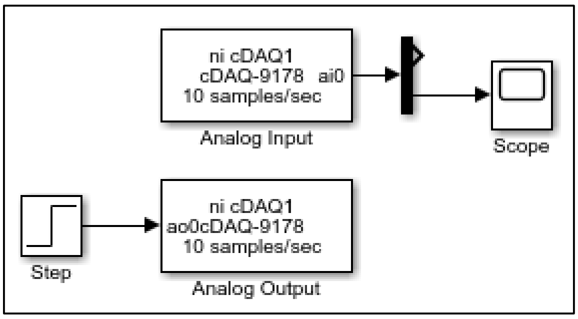


Figure 7: MATLAB Simulink Interface sensor and actuator block diagram

After that, the voltage liquid level calibration is very important to be obtained before converting the voltage signal into a level (mm) value with appropriate measurement. The procedure to performed calibration level sensor tank 1 on CE105 as stated below:

1. The experimental unit for liquid level sensor calibration was illustrated in Figure 6 but with a manual input signal for fill full the tank with liquid. Data acquisition device connected between PC and plant CE105.
2. The first process is to fill the tank with liquid until full.
3. After that, the water from the tank slowly released by opening Valve B for tank1 (Valve A and B closed).
4. The reading of voltage was recorded from 250 mm to 0 mm.
5. The liquid output level defined at CE105 by manual reading and checked the voltage using Scope block as shown in Figure 7 and also using digital multimeter during the point.

2.7 Open Loop Experiment

Open loop experiment is an important part before further analysis to describe the behaviour of the system. The collected data must be informative and able to represent the system very well. Practically, the data collection is always repeated if the data is not enough to describe the system well.

The open loop experiment was set Valve A at position 5, Valve B at position 1 and Valve C at position 1.5. The behaviour of the tank system is very slow so that the sampling time is set 10 per second. The experiment with input PRBS perturbation was conducted at tank 1. Three data sets were collected based on different sample time of PRBS. The three of data sets were collected at starting until 300 second time range. The three data sets named Exp1, Exp2 and Exp3.

2.7.1 The Pseudorandom Binary Sequence Pertubation

The advantageous of using Pseudorandom Binary Sequence (PRBS) input signal is similar to white noise and the signal only operate two values, which is 0 to 10 for this experiment and this technique is practical in the most industrial process. Besides that, the signal can be set in any frequency ranges that correspond to the process dynamic system which is important for control design [3].

For this experiment, created PRBS signal by using Simulink MATLAB shown in Figure 8. Random Number block is used to generate normally distributed random numbers. Then using block ‘Compare to Zero' to create binary random wave signal. By applying different ‘sample time' in Random Number block, the output will result in a different frequency of PRBS signals. For the collection of data liquid level tank, the several frequency sets will be chosen which affects the dynamics of the system under test.

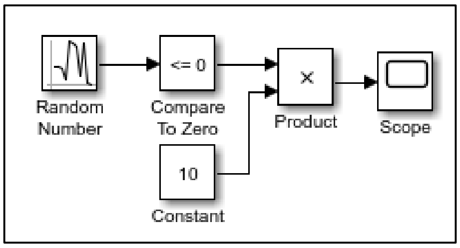


Figure 8: PRBS signal block Simulink

Simulink block as Figure 9 shown experiment open loop has been executed to obtain the input and output of liquid level of CE105. The input data PRBS it sends to DAQ card through analog output port ‘ao0’. The input signal supply voltage to the motor pump where input signal 0 to 10v. For the output data, tank 1 was connected to port ‘ai0' and tank2 to ‘ai1' at Analog input block. The data collected is recorded through IDDATA SINK block that saves at Workspace. In this experiment to create a model for CE105, three input and output dataset was collected at a different frequency of PRBS. The input and output data have been sampled at 10 samples per second because of slow response CE105 system.

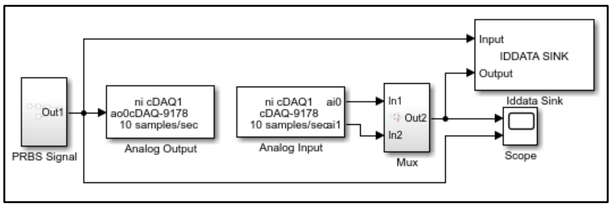


Figure 9: Simulink Data collection block

2.8 Model Estimation

Model estimation is a mathematical model from the dataset of open loop experiment. System Identification toolbox is used to estimate the characteristic and dynamic system of CE105 by relating the relationship between the input and output dataset. Estimation model technique used is non-linear ARX model because of nonlinearity dynamic system of CE105.

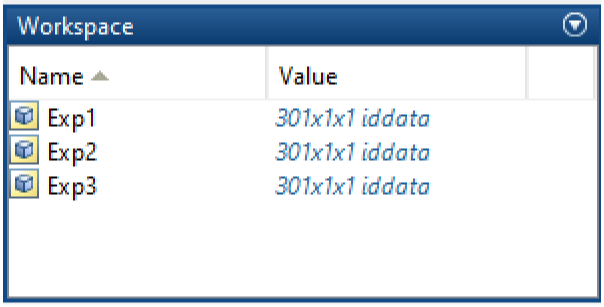
2.9 Model Validation

Model validation is to check the fit of the measured data and model estimation data. The parameters of model structures are adjusted until the model output meet the best fit of output experiment data. For nonlinear ARX toolbox required to adjusted delay for input channels.

2.10 System Identification Toolbox

System identification toolbox provides in MATLAB function and Simulink blocks for constructing mathematical models of nonlinear dynamic systems from measured input and output data. For this experiment, nonlinear dynamic system in the ARX model is used because of it easier and most ‘best fits' to estimate dynamic system compare to others model. The nonlinear ARX model can directly transfer to the Simulink for plant modelling by using Nonlinear ARX block. The procedures of System Identification toolbox will be shown step by step.

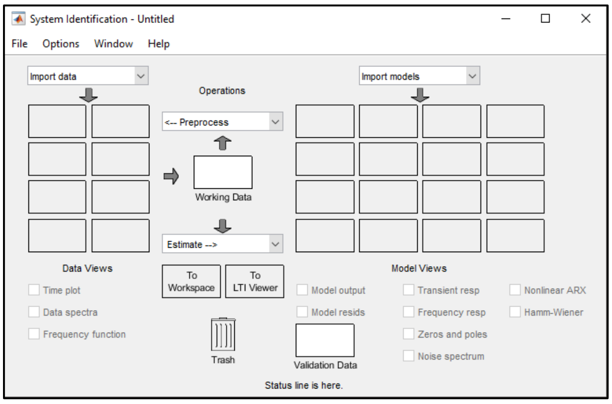
I. In workspace, input and output dataset generated from the Open Loop experiment. The input-output dataset is named as the Exp1, Exp2 and Exp3. The variable is as shown in Figure 10.


Workspace

Name ▲	Value
Exp1	301x1x1 iddata
Exp2	301x1x1 iddata
Exp3	301x1x1 iddata

Figure 10: Input-Output data experiment at Workspace

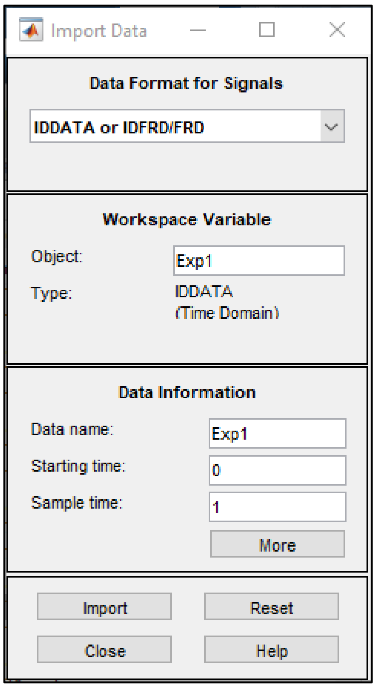
II. System Identification Toolbox located in application Control System Design and Analysis MATLAB 2018a. To open System Identification toolbox as shown in Figure 11, type "systemIdentification" in the command window.



Status line is here.

Figure 11: System Identification Toolbox

III. At the ‘Import Data’ window, select ‘Data Object’. Then insert object name same as workspace variable. Configure the starting time to 0 and sample time to 1 and click ‘Import’ to import data as shown in Figure 12. Repeat this step to import all dataset.



IDDATA or IDFRD/FRD

Object: Exp1

Type: IDDATA (Time Domain)

Data name: Exp1

Starting time: 0

Sample time: 1

Figure 12: Import Data

IV. The dataset of the System Identification Toolbox can be displayed by ticking ‘Time Plot' box as shown in Figure 13.

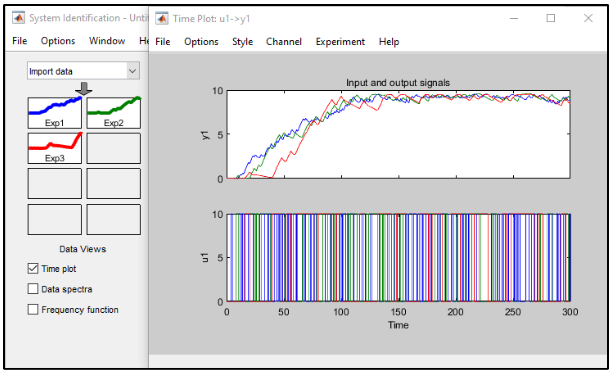


Figure 13: Display dataset signals

V. Drag and drop the input-output data into ‘Working Data' window and ‘Validation Data' window for model estimation. The unwanted data can just simply drag and drop into the trash icon. At the ‘Estimate' window, select the desired model structure to be estimated as shown in Figure 14. For this project, the model used is a Nonlinear ARX model and the setting are configured to get the best fit model.

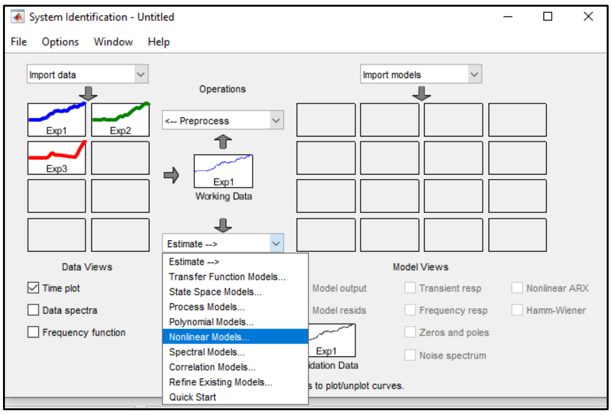
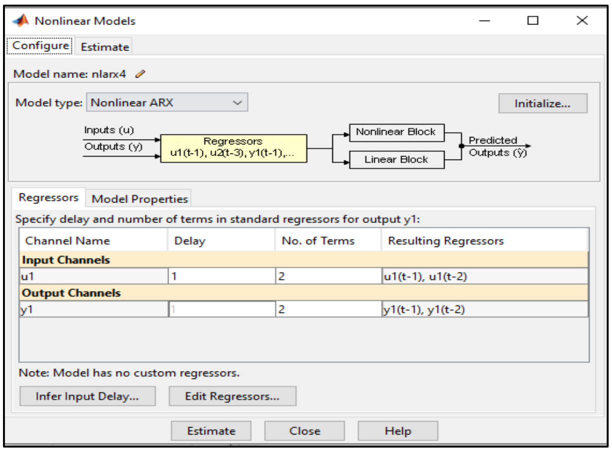


Figure 14: Select Model Structure

VI. For Nonlinear ARX setting the time Delay at Input Channels u1 to get the best fit. Then click ‘Estimate' to create the model as shown in Figure 15.



Model name: nlarx4

Model type: Nonlinear ARX

Specify delay and number of terms in standard regressors for output y1:

Channel Name	Delay	No. of Terms	Resulting Regressors
Input Channels			
u1	1	2	u1(t-1), u1(t-2)
Output Channels			
y1	1	2	y1(t-1), y1(t-2)

Note: Model has no custom regressors.

Figure 15: Nonlinear ARX model configure

VII. The estimated models will display at Model Views and tick Model output for analysis the model best fits with Validation Data. Figure 16 showing the estimated models located.

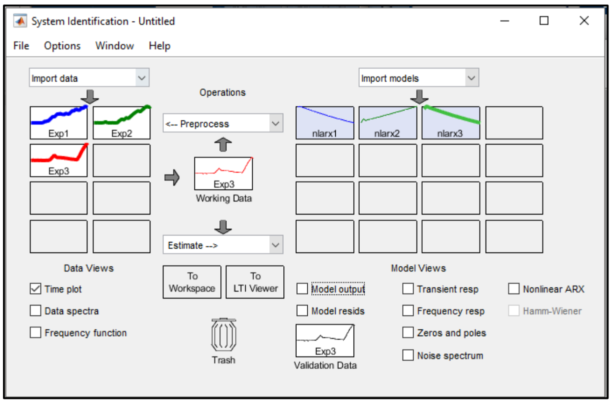
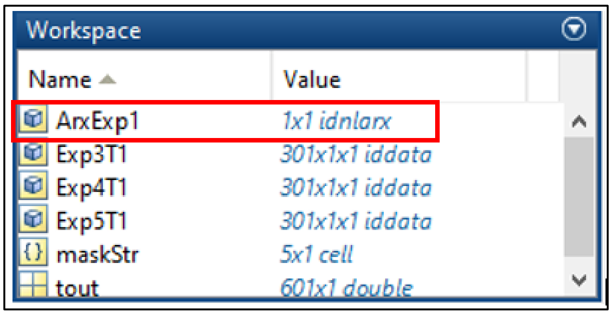


Figure 16: Model Views estimation platform

VIII. Drag and drop the desired estimated model named as ‘ArxExp1' to the ‘To Workspace' window as shown in Figure 17. The exported data at workspace will be used for nonlinear ARX block at Simulink.



Name	Value
ArxExp1	1x1 idnlarx
Exp3T1	301x1x1 iddata
Exp4T1	301x1x1 iddata
Exp5T1	301x1x1 iddata
maskStr	5x1 cell
tout	601x1 double

Figure 17: Exported estimated model

3. Results

The data level in mm and voltage level sensor was collected represent in Table 2. Figure 18 and Table 3 shown the plot of data calibration by using curve fitting toolbox.

Table 2: Result for liquid level sensor verification

Level (mm)	Voltage Tank 1 (V)
0	0
10	0.48
20	0.8
30	1.16
40	1.6
50	1.95
60	2.35
70	2.7
80	3.15
90	3.46
100	3.88
110	4.22
120	4.6
130	4.95
140	5.3
150	5.7
160	6.2
170	6.4
180	6.8
190	7.2
200	7.52
210	7.85
220	8.2
230	8.6
240	9
250	9.2

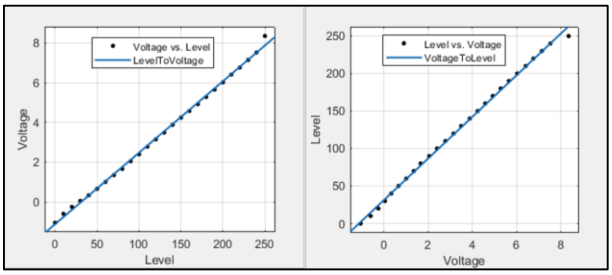


Figure 18: Polynomial fitting curve sensor Voltage and Level

Table 3: Result from curve fitting tool MATLAB

Result Voltage to Level	Result Level to Voltage
Linear model Poly1: f(x) = p1*x + p2 Coefficients (with 95% confidence bounds): p1 = 27.01 (26.75, 27.26) p2 = -3.036 (-4.427, -1.645) Goodness of fit: R-square: 0.9995	Linear model Poly1: f(x) = p1*x + p2 Coefficients (with 95% confidence bounds): p1 = 0.03701 (0.03666, 0.03736) p2 = 0.1147 (0.06412, 0.1653) Goodness of fit: R-square: 0.9995

Based on Table 3, the calibration curve is estimated by using the first-order polynomial. It is sufficient to represent the calibration curve by producing good R^2 value that equal to 0.9995. The fitted first-order polynomial for voltage to level is given by Equation 3.1 and for the level to voltage is given by Equation 2.

$$L = 27.01V - 3.036 \tag{1}$$

$$V = 0.03701L + 0.1147 \tag{2}$$

Where L denote the level (mm) and V is the measured voltage.

In Figure 19 to Figure 21 shown the result data collected from the plant liquid tank system by using input PRBS. The data Exp1, Exp2 and Exp3 consist of 300 sample data of liquid level until a steady state at maximum level which is 250 mm. The output data was presented in voltage, the voltage-level converter will be applied at Simulink controller design. All the dataset collected for system identification purposed.

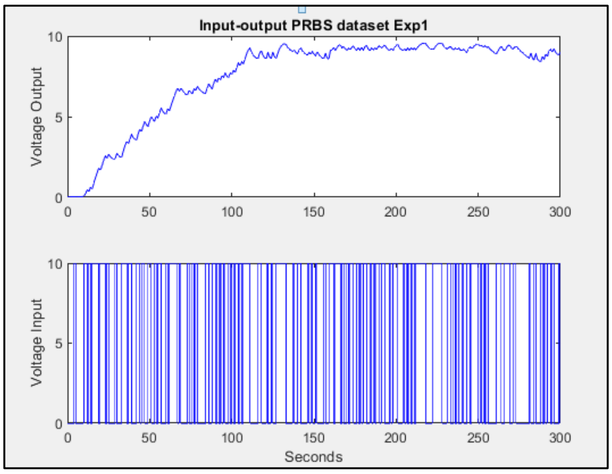


Figure 19: Input-Output PRBS dataset for Exp1

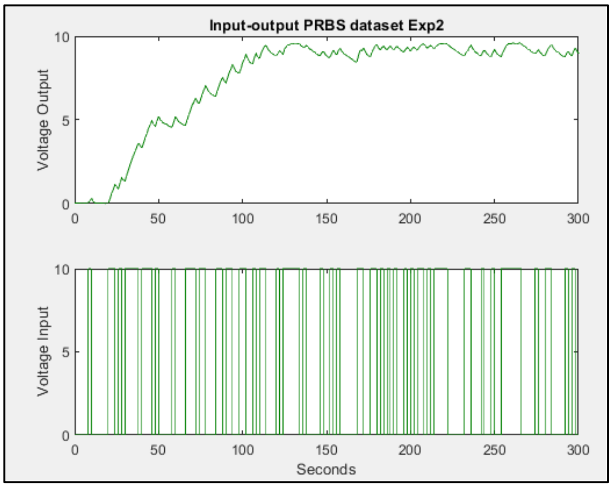


Figure 20: Input-Output PRBS dataset for Exp2

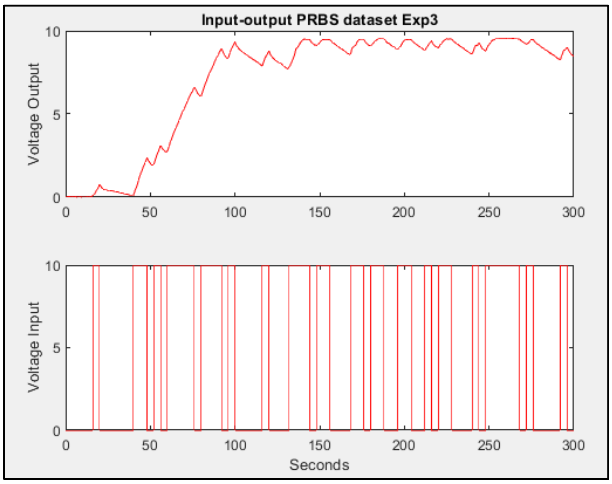


Figure 21: Input-Output PRBS dataset for Exp3

3.1 **Nonlinear ARX System Identification Toolbox**

The model estimated using system identification toolbox technique. Three models were estimated by using nonlinear ARX and the models named as ArxExp1, ArxExp2 and ArxExp3. Figure 22 to Figure 24 showed the best fit value for model estimation. The validation data set referred to dataset Exp1, Exp2 and Exp3. The validation dataset used the same as the dataset for model estimation because this validation test on different input and output condition that based on the PRBS input set. So, the best data fits were ArxExp1 because every validation experiment showed the best value data fit as shown in Table 4.

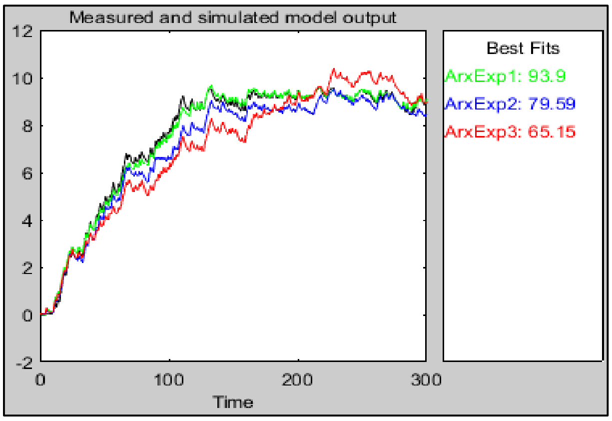


Figure 22: Model validation result on Exp1 data

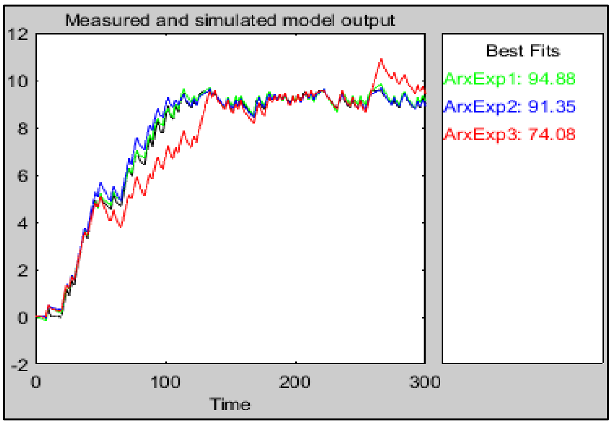


Figure 23: Model validation result on Exp2 data

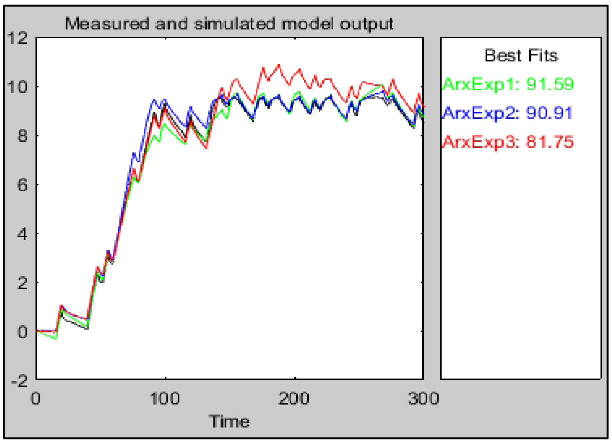


Figure 24: Model validation result on Exp3 data

Table 4: Model estimation and validation result

Model	Validation Exp1	Validation Exp2	Validation Exp3
ArxExp1	93.9	94.88	91.59
ArxExp2	79.59	91.35	90.91
ArxExp3	65.15	74.08	81.75

4. **Summary**

In general, the project has met the objectives. System identification has been done on the liquid CE105 coupled tanks system to obtain the nonlinear ARX model. The model can predict the outputs of the dynamic system than applied to simulation. The nonlinear ARX model was successful to describe the behaviour and dynamic of the system.

The liquid level CE105 coupled tanks system has been operated as expected. The system has been monitored and controlled through Data Acquisition card. The voltage to level calibration was done by using a first-order polynomial model. Curve fitting toolbox used to calibration the sensors.

The PRBS perturbation with different frequency was set up for input dataset than output voltage level has been collected. The different input and output datasets obtained from the plant named as data Exp1, data Exp2 and data Exp3. All the dataset collected time in the range 300 seconds. All data were estimated by using the nonlinear ARX model through system identification toolbox, data Exp1 has been successfully fitted for the best model output.

5. **Recommendations**

In this project, system identification ARX model can be improve by using particle swarm optimization (PSO). The PSO algorithm have a large impact on optimization performance.

The data acquisition platform built by National Instruments is too expensive that the students unable to afford. Hence, data acquisition platform should be replaced to Arduino board for future work. Challenging by using Arduino board are the Arduino working voltage only in range 0 to 5V, so require to implement operational amplifier to improve the voltage to 10v maximum. Besides that, to reduce 10 voltage operating range from CE105 coupled tanks system is by using voltage divider so that not damage the Arduino board.

Acknowledgement

Acknowledgements and Reference heading should be left justified, bold, with the first letter capitalized but have no numbers. Text below continues as normal.

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