CHAPTER 6

CLOSED LOOP STUDIES USING REAL TIME EXPERIMENTAL SETUP

6.1 INTRODUCTION

The practical implementation of NDMC and GSA-DMC schemes applied to an experimental setup of TCTILS are developed in the present work. The laboratory setup of TCTILS is fabricated and interfaced to personal computer using National Instruments multi function PC based data acquisition board PCI 6238. The NDMC and GSA-DMC schemes are implemented on personal computer using LabVIEW 2009 and MATLAB R2009a software packages. The research is carried out to investigate the servo performance capability of NDMC and GSA-DMC schemes.

6.2 EXPERIMENTAL SETUP OF TCTILS

The experimental setup of TCTILS is shown in Figure 6.1 which is designed and fabricated to demonstrate NDMC and GSA-DMC schemes. The experimental setup of TCTILS is assembled using real industrial components. The water level in TANK1 and TANK2 are measured by ABB make (Model: 262B/D/V/P) differential pressure transmitters LT1 and LT2 respectively. The output of level transmitters is in the form of 4-20 mA current signals. CV1 and CV2 are two control valves fitted with ABB make smart valve positioner which will take 4 – 20 mA current signal as a control input signal. CV1 and CV2 are 1 inch control valves with linear characteristics. Level transmitters
and control valves are interfaced with PC with the help of National Instruments NI 6238 Multifunction DAQ board (National Instruments 2006) which is a PCI compatible PC based data acquisition board. It has eight differential current input channels (AI-0 to AI-7) and two current output channels (AO-0 to AO-1) with 16-bit resolution. The level transmitters are interfaced with two differential current input channels (AI-0 and AI-1) of the NI 6238 Multifunction DAQ board. The control output signals in the form of 4-20 mA current signals are generated from two current output channels (AO-0 and AO-1) of NI 6238 Multifunction DAQ board and are connected to control valves CV₁ and CV₂ respectively.

Figure 6.1 Experimental setup of TCTILS

6.2.1 Differential Pressure Transmitter

The level transmitter used in TCTILS is an ABB make 262B type Differential Pressure Transmitter which is shown in Figure 6.2. This is a modular type field mounted, microprocessor based electronic transmitter, using unique inductive sensing element. The high pressure end is connected to bottom of the tank and low pressure end is open to atmosphere since the tank is kept open at the top. This provides accurate and reliable measurement of
differential pressure and thereby giving level of the liquid in tank. This SMART transmitter provides 4-20 mA current output. This transmitter supports HART protocol for remote re-ranging, calibration and diagnostics. Model 262B is a differential pressure transmitter with a maximum working pressure of up to 3045psi. It has a reliable sensing system coupled with the very latest digital technologies, providing a large turn down ratio up to 100:1. The configuration is flexible and is provided locally via local keys combined with LCD indicator or via hand held terminal or PC configuration platform.

![Figure 6.2 ABB make 262 B differential pressure transmitter](image)

The other specifications are listed in Table 6.1.

**Table 6.1 Specifications of differential pressure transmitter**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base accuracy</td>
<td>±0.075%</td>
</tr>
<tr>
<td>Span limits</td>
<td>0.05 to 16000 kPa</td>
</tr>
<tr>
<td>Multiple protocol availability</td>
<td>provides integration with HART®, PROFIBUS PA and FOUNDATION Fieldbus platforms offering interchange ability and transmitter upgrade capabilities</td>
</tr>
<tr>
<td>Full compliance with</td>
<td>PED Category IV – suitable for safety accessory application</td>
</tr>
</tbody>
</table>
6.2.2 Control Valve with Positioner

The two control valves used in TCTILS are manufactured by R.K. Industries and are shown in Figure 6.3. These control valves are used to regulate flow rates $F_{IN1}$ and $F_{IN2}$. The specifications of a control valve used in TCTILS are listed in Table 6.2.

![Control valve with positioner](image)

**Figure 6.3 Control valve with positioner**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Pressure Range</td>
<td>Vacuum to 150 PSIG</td>
</tr>
<tr>
<td>Material Valve Body</td>
<td>Gun metal</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>0º F to 140º F</td>
</tr>
<tr>
<td>Valve ports</td>
<td>1&quot;</td>
</tr>
<tr>
<td>Valve Type</td>
<td>Normally Closed</td>
</tr>
<tr>
<td>Actuating air pressure</td>
<td>0 to 80 psi</td>
</tr>
<tr>
<td>Valve positioner</td>
<td>ABB make</td>
</tr>
<tr>
<td>Current input</td>
<td>4 – 20 mA current signal</td>
</tr>
<tr>
<td>Valve position output</td>
<td>4 – 20 mA current signal</td>
</tr>
</tbody>
</table>

6.2.3 NI 6238 Multifunction Data Acquisition board

The M Series NI 6238 Multifunction Data Acquisition board features eight differential Analog Input (AI) channels, two Analog Output (AO) channels, two counters, six lines of Digital Input (DI), and four lines of
Digital Output (DO). NI 6238 Multifunction Data Acquisition hardware digitizes analog input signals, performs D/A conversions to generate analog output signals, and measures and controls digital I/O signals. The analog input and output signals are in the form of 4-20mA current signal. The NI 6238 Multifunction Data Acquisition board and its functional block diagram are shown in Figure 6.4.

![NI 6238 Multifunction Data Acquisition board](image1)

![Functional block diagram](image2)

Figure 6.4 (a) NI 6238 Multifunction Data Acquisition board (b) Functional block diagram
Some key features of this board include the following:

- Flexible AI and AO sample and convert timing
- Many triggering modes
- Independent AI and AO FIFOs
- Generation and routing of RTSI signals for multi-device synchronization
- Generation and routing of internal and external timing signals
- Two flexible 32-bit counter/timer modules with hardware gating
- Static DIO signals
- PLL for clock synchronization
- PCI/PXI interface
- Independent scatter-gather DMA controllers for all acquisition and generation functions

The pin configuration details of NI 6238 connector with interfacing of LTs and CVs is shown in Figure 6.5.
The analog input and output specifications are listed in Table 6.3.

Table 6.3  Analog input and output specifications of PCI 6238

<table>
<thead>
<tr>
<th>Specification</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Analog Input Specification</strong></td>
<td></td>
</tr>
<tr>
<td>Number of channels</td>
<td>8 differential current inputs</td>
</tr>
<tr>
<td>Ground reference</td>
<td>Al GND</td>
</tr>
<tr>
<td>ADC resolution</td>
<td>16 bits</td>
</tr>
<tr>
<td>Sampling rate Max</td>
<td>250 kS/s</td>
</tr>
<tr>
<td>Timing resolution</td>
<td>50 ns</td>
</tr>
<tr>
<td>Input coupling</td>
<td>DC</td>
</tr>
<tr>
<td>Input range</td>
<td>±20 mA</td>
</tr>
<tr>
<td><strong>Analog Output Specification</strong></td>
<td></td>
</tr>
<tr>
<td>Number of channels</td>
<td>2 current outputs</td>
</tr>
<tr>
<td>Ground reference</td>
<td>AO GND</td>
</tr>
<tr>
<td>DAC resolution</td>
<td>16 bits</td>
</tr>
<tr>
<td>Maximum update rate</td>
<td>500 kS/s</td>
</tr>
<tr>
<td>1 channel</td>
<td>450 kS/s per channel</td>
</tr>
<tr>
<td>2 channels</td>
<td>50 ns</td>
</tr>
<tr>
<td>Timing resolution</td>
<td>0 to 20 mA</td>
</tr>
</tbody>
</table>
6.3 SERVO PERFORMANCE

For experimental study, NDMC and GSA-DMC schemes are implemented using LabVIEW 2009 and MATLAB R2009a software packages. The algorithms for NDMC and GSA-DMC schemes are implemented using MATLAB programs. The acquisition of tank levels, sending control signals to control valves and interfacing with MATLAB programs are implemented using LabVIEW programs. Unit step response coefficients for each controller output to measured process variable pair \((u_1, h_1), (u_1, h_2), (u_2, h_1), (u_2, h_2)\) are collected from TCTILS experimental setup in off-line. Using center point of each linear regime as a operating point, the unit step response coefficients are collected for each linear DMC. The sampling time is set to 0.2 second. The tuned controller parameters for practical implementing of GSA-DMC and NDMC schemes in TCTILS experimental setup are presented in Table 6.4.

Table 6.4 Tuned controller parameters for practical implementation of GSA-DMC and NDMC schemes in TCTILS experimental setup

<table>
<thead>
<tr>
<th>DMC parameters</th>
<th>DMC1</th>
<th>DMC2</th>
<th>DMC3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prediction Horizon</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Model Horizon</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Control Horizon</td>
<td>75</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Move Suppression</td>
<td>(\lambda_1)</td>
<td>1</td>
<td>2.1</td>
</tr>
<tr>
<td>coefficient</td>
<td>(\lambda_2)</td>
<td>1</td>
<td>0.65</td>
</tr>
<tr>
<td>Control Variable</td>
<td>(\gamma_1)</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>weights</td>
<td>(\gamma_2)</td>
<td>0.1</td>
<td>0.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Generalised bell MFs for T-S FIS1</th>
<th>Generalised bell MFs for T-S FIS2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linguistic variable</td>
<td>Tuned Parameter value</td>
</tr>
<tr>
<td>-----------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>h11</td>
<td>[4 7 5]</td>
</tr>
<tr>
<td>h12</td>
<td>[9.9 21.5 17.03]</td>
</tr>
<tr>
<td>h13</td>
<td>[22 43 38]</td>
</tr>
</tbody>
</table>
The setpoint variations as shown in Figure 6.6(a) are introduced for assessing tracking capability of NDMC and GSA-DMC schemes. The variation in process outputs and controller outputs are shown in Figure 6.6 (a) and 6.6(b) respectively. From the Figure 6.6(a), it can be inferred that, NDMC scheme is able to maintain tank levels $h_1$ and $h_2$ at respective setpoints better than GSA-DMC scheme. The NDMC scheme produces response with faster rise time and settles to the setpoint faster compared to GSA-DMC scheme. From the Figure 6.6(b), it can be inferred that, NDNC scheme produces control signal with lesser overshoot and oscillation compared to GSA-DMC scheme.

![Figure 6.6 Real time servo response of TCTILS with GSA-DMC and NDMC schemes](image)

(a) Process output
(b) Controller output

Figure 6.6 Real time servo response of TCTILS with GSA-DMC and NDMC schemes (a) Process output (b) Controller output
The values of performance indices for real time servo response of GSA-DMC and NDMC schemes are computed and presented in Table 6.5. From Table 6.5, it is inferred that the values of performance indices for NDMC scheme are found to be considerably less than GSA-DMC scheme.

Table 6.5  Comparison of performance indices of real time servo response of GSA-DMC and NDMC schemes in TCTILS experimental setup

<table>
<thead>
<tr>
<th>Level</th>
<th>Performance Indices</th>
<th>NDMC</th>
<th>GSA-DMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>h₁</td>
<td>ISE</td>
<td>1.9216e+03</td>
<td>2.0288e+03</td>
</tr>
<tr>
<td></td>
<td>IAE</td>
<td>1.7639e+03</td>
<td>2.4498e+03</td>
</tr>
<tr>
<td></td>
<td>ITAE</td>
<td>1.7570e+05</td>
<td>3.7262e+05</td>
</tr>
<tr>
<td>h₂</td>
<td>ISE</td>
<td>1.2750e+04</td>
<td>1.5209e+04</td>
</tr>
<tr>
<td></td>
<td>IAE</td>
<td>1.3265e+03</td>
<td>1.6512e+03</td>
</tr>
<tr>
<td></td>
<td>ITAE</td>
<td>1.3529e+05</td>
<td>1.8067e+05</td>
</tr>
</tbody>
</table>

6.4 COMPARISON BETWEEN SIMULATED AND REAL TIME SERVO RESPONSES

In order to compare the similarity of the real time servo response produced from TCTILS experimental setup and simulated servo response produced from TCTILS developed using the nonlinear first principle model (Equations (2.12) and (2.13)), both GSA-DMC and NDMC schemes are developed in which linear DMCs are designed using step response coefficients collected from TCTILS experimental setup. Whereas in Chapter 5, linear DMCs are designed using step response coefficients collected from TCTILS developed using the nonlinear first principle model.
The setpoint variations as shown in Figure 6.7(a) are introduced for assessing the tracking capability of the NDMC and GSA-DMC schemes and comparing with real time servo response as shown in Figure 6.6. The variation in process outputs and controller outputs are shown in Figure 6.7 (a) and 6.7(b) respectively. From the Figure 6.7(a), it can be inferred that, NDMC scheme is able to maintain tank levels $h_1$ and $h_2$ at respective setpoints better than GSA-DMC scheme. From the Figure 6.6(a) and 6.7(a), it is inferred that both real time servo response and simulated servo response are under damped in nature.

![Figure 6.7 Servo response of TCTILS with GSA-DMC and NDMC schemes designed using step response coefficients collected from TCTILS model](image)

(a) Process output (b) Controller output
6.5 SUMMARY

The TCTILS experimental setup is constructed using real industrial components. GSA-DMC and NDMC schemes are implemented in TCTILS experimental setup using LabVIEW and MATLAB software packages. From the experimental results it is observed that performances of NDMC scheme at all operating points are found to be better than GSA-DMC scheme, as there is quicker rise time, reduced interaction effect and settles to the setpoint faster. The experimental work is revealed that NDMC scheme is an effective and practical approach to nonlinear process control systems like TCTILS, providing excellent control performance and helps to compensate for dynamic coupling effect in different operating regimes despite the variations in setpoint. With its significant and simple controller structure, and excellent performance, the NDMC strategy presents to be a promising approach to nonlinear process control, alternative to existing GSA-DMC strategy in the process industry. Hence MMAC strategy is a promising tool for design and practical implementation to control interacting nonlinear systems like TCTILS.

Decentralised PI controllers (ADD-PI and NADD-PI controllers) are also tried on TCTILS experimental setup. From the experimental results it is observed that performances of the NDMC scheme at all operating points are found to be better than decentralised PI controllers as there is quicker rise time, reduced interaction effect and settles to the setpoint faster.

The summary, conclusion and future scope of the present work are discussed in detail in the next chapter.