Ain Shams University

Faculty of Engineering

Position Control of Pneumatic Actuators Using Pulse Width Modulation Technique

Thesis Submitted to the Faculty of Engineering Ain Shams University

For Partial Fulfillment of the Degree of Master of Science in Mechanical Power Engineering

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STATEMENT

This thesis is submitted to Ain Shams University in partial fulfillment of the requirement for the M.Sc. Degree in Mechanical power engineering. The work included in this thesis has been carried out by the author in mechanical power engineering department, Ain Shams University. No part of the thesis has been submitted for a degree or a qualification at other university or institute.

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ABSTRACT

Experimental and theoretical study is carried out to control the position of a pneumatic cylinder using online Self-Tuning PID controller (denoted as STNPID controller) based on neural network with back propagation scheme.

The inputs to the STNPID are the tracking error, set point and control action, while the outputs of the neural network are the optimized gains k_p, k_i and k_d.

The STNPID uses neural networks for online tuning of the PID controller gains depending on the environmental and system requirements in order to make the nonlinear system unaffected by the unpredictability of system's parameters and disturbances such as noise.

High speed digital control valves (operating at frequencies up to 150 Hz) are implemented to accurately control the position of the cylinder piston using Pulse Width Modulation (denoted as PWM) technique.

Results show that the STNPID controller is able to track both constant and variable set point trajectories efficiently by the pneumatic actuator system.

Comparison of the results of STNPID with the conventional PID controller shows that the self-tuning of the PID gains can cope with the nonlinearity of the pneumatic system which is incompatible with the linear behavior of the conventional PID controller. The tracking response for STNPID controller is enhanced with less overshoot and less steady state errors compared to the conventional PID. For square wave, the maximum overshoot is improved from18.83 % for PID to 2.67 % for STNPID. The steady state error is also improved from 9.42 % to 2.67 %.

The oscillation behavior for the sinusoidal response of the conventional PID controller is damped by the STNPID controller and better response is observed. Also, the actuator acts smoothly and uniformly compared to the conventional PID controller with less oscillatory actuator response.

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A	Cylinder area
A_{cr}	Right side cylinder area
A_{cl}	Left cylinder area
A_s	Stem area
a	Acceleration
a_v	Valve area
c	Sonic speed
c_1	Speed of sound in air at nozzle inlet
c_2	Speed of sound in air at nozzle throat
C_d	Coefficient of discharge
C_p	Specific heat at constant pressure
C_v	Specific heat at constant volume
d	Exact differentials
E_{sys}	System energy
e	Error
e_{rms}	Root mean square error
F	Force
F_e	Equivalent force
F_{ext}	External forces
f	Sigmoid function
F_f	Static friction force
F_v	Coefficient of viscous friction
H	Enthalpy
h	Step size
h_i	Inlet specific enthalpy
h_o	Outlet specific enthalpy
J	Cost function

k_d	Derivative gain
k_i	Integral gain
k_p	Proportional gain
k_{pr}	Runge kutta right pressure coefficient
k_{pl}	Runge kutta left pressure coefficient
k_{Tr}	Runge kutta right temperature coefficient
k_{Tl}	Runge kutta left temperature coefficient
k_v	Runge kutta velocity coefficient
k_y	Runge kutta displacement coefficient
L	Work distance
M	Mach number
m	Mass
m_g	Mass of the gas
m_p	Piston mass.
m_{vl}	Left valve mass flow rate
m_{vr}	Right valve mass flow rate
N	Number of wave cycles
net_x	Input given by STNPID controller
o	Neuron output
p_1	Inlet flow pressure.
p_2	Outlet flow pressure
P_{atm}	Atmospheric pressure
P_b	Back pressure
P_c	Cylinder pressure
P_{cl}	Left side cylinder pressure
P_{cr}	Right side cylinder pressure
P_{crt}	Critical pressure
P_d	Downstream pressure

$\mathbf{P_s}$	Supply pressure
$\mathbf{P_{th}}$	Throat pressure
$\mathbf{P_u}$	Upstream pressure
Q	Heat
r	Three inputs matrix
R	Gas constant
t	Time
T	Air temperature
$\mathbf{T_1}$	Inlet flow temperature
$\mathbf{T_2}$	Outlet flow temperature
$\mathbf{T_b}$	Back temperature
$\mathbf{T_{cl}}$	Left cylinder temperature
$\mathbf{T_{cr}}$	Right cylinder temperature
$\mathbf{T_{crt}}$	Critical temperature
$\mathbf{T_d}$	Derivative time in seconds
$\mathbf{T_i}$	Integral time in seconds
$\mathbf{T_{th}}$	Throat temperature
$\mathbf{T_{ur}}$	Right upstream temperature
$\mathbf{T_{ul}}$	Left upstream temperature
U	Internal energy
u(t)	Control action
$\mathbf{u_1}$	Inlet flow velocity
$\mathbf{u_2}$	Outlet flow velocity
V	Volume
$\mathbf{v_p}$	Piston velocity
$\mathbf{\Delta w}$	Increment of the connection weight

w_{ji}	Connection weights from the input neuron i at the input layer to the neuron at the hidden layer
w_{kj}	Connection weights from the hidden neuron j at the input layer to the neuron at the output layer
y_a	Actual value
y_c	Actual actuator position
y_d	Desired value
y_{max}	Maximum position

GREEK SYMBOLS

α	Momentum term
γ	Ratio of specific heats
δ	Back propagating error
η	Learning rate
θ	Bias
ν	Mean fluid velocity
ν_1	Inlet velocity
ν_2	Output velocity
ρ_1	Upstream density
ρ_2	Downstream density
$\sum$	Sigma