Optimal Design and Implementation of a digital controller for frequent Set-point & Load Changes

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Abstract: The aim of this work is to design a Set-point weighted PID controller that is adaptive in nature; so as to be able to tackle varying set-point and changing loads, with the intention of solving the problem of set-point kick and any other problems resulting because of in-operation variations.

The system being proposed is microcontroller based controller (STM32F4) programmed using Keil. The data required for initial tuning is gained using MATLAB SIMULINK simulations. The result being improved performance over regular ZN-tuned PID.
Keywords: PID, Set-point weighted, Zn-tuned PID, Microcontroller.

I. INTRODUCTION:

PID has being the go to method to control a process, where a process output has to follow a set-point; which is what the aim of most of the control processes are, when it simplified to its bear minimum. Another it is widely accepted is due the simplicity involved in tuning it, which is quiet straightforward. Of the various tuning relations, Ziegler-Nichols(ZN)[1] settings are considered to be most familiar for determining good initial conditions. During steady state response, ZN tuned PID controllers are found to provide improved performance compared to transient response. Another advantage of ZN- tuned is that is independent of process model. Alternative to it relay tuning[2] is to be used when, the process to be controlled cannot be pushed near its critical gain.

But the use of a conventional PID brings with some disadvantages, one of which is the large overshoot in the beginning of its operation of following the set-point. This problem especially prevalent in higher order processes, where to minimize the large oscillations produced by the higher order processes under both the set point change and load variation is an open challenge to the control engineers[3] so, the use of conventional PID, is really harmful for a system that has to operate at various set-points in its operation; as these frequent overshoots harm the control device (eg.: actuator), disturbs the process and in some cases can also push the system towards oscillation causing it to go unstable.

Set point filtering and set point weighted techniques [4] are suitable options for tackling this kind of problem of which set-point weighted is inherently better suited to be implemented on a microcontroller. Thus, literature review [5-] is focused on set point weighted techniques . The nature of SPW in [5] is Fixed wherein the weights cannot be varied.[6] talks about Variable Set point weighting (VSPW) which uses three different values of the weighting factor, resulting in better results compared to FSPW. Another set point weighted is proposed in [7] where the weighting factor is obtained by minimizing the integral square error of the controlled variable.

Following this, [8-9] give a sigmoid function [8] and implementation [9] of the same. Form of this function makes it a viable choice to be used in the microcontroller to be designed. Similarly [10-11] gives another method [10] and implementation [11] based on fuzzy logic.

This proposed system, is be based on the idea presented in [8], with the goal to streamline it into a single controller device; not needing an overseeing high powered computing device(PC).

II. PROPOSED SYSTEM:

Block diagram of the structure to be used is shown in Fig. 1. The dotted boundary shows the computational mechanism of dynamic weighting factor (β_f) [8], which is calculated using the sigmoid function based on the change of error as seen in the figure. Thus, the weighted set-point (y_f) is dynamically altered in-operation by the weighting factor.

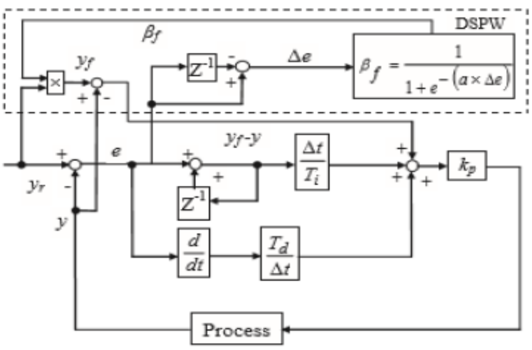


Fig 1: Block Diagram of DSPW PID Controller [8]

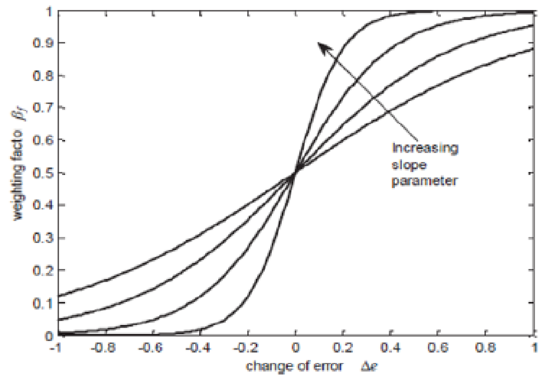


Fig 2: Relationship between change of error and weighting factor [8]

The proposed scheme, uses bumpless PID algorithm [12] in Z-domain for implementing PID in the microcontroller selected:

$$u(n) = s_0 e(n) + s_1 e(n-1) + s_2 e(n-2) + u(n-1)$$

Where;

$$s_0 = K_p[1 + \frac{T_s}{2T_I} + \frac{T_d}{T_s}] \qquad s_2 = K_p \frac{T_d}{T_s}$$

$$s_1 = K_p[1 + \frac{T_s}{2T_I} - 2\frac{T_d}{T_s}]$$

And the DSPW PID is based on the variation proposed on Basic PID is this:

$$u(n) = s_0 e(n) + s_1 e(n-1) + s_2 e(n-2) + u(n-1) + a - b$$

Where;

$$s_0 = K_p[\frac{T_s}{2T_I} + \frac{T_d}{T_s}] \qquad a = K_p[\beta_f r(n) - y(n)]$$

$$s_1 = K_p[\frac{T_s}{2T_I} - 2\frac{T_d}{T_s}] \qquad b = K_p[\beta_f r(n-1) - y(n-1)]$$

$$s_2 = K_p \frac{T_d}{T_s}$$

In this the sigmoid functionβ_f, is given as;

$$\beta_f(\Delta e) = \frac{1}{1 + e^{-(a \times \Delta e)}}$$

Here a is a slope parameter of the sigmoid function. Due to, multiplicative form of a and Δe, error also plays a role in the shape of the sigmoid as seen in Fig. 2.

This proposed system has been made made following these steps:

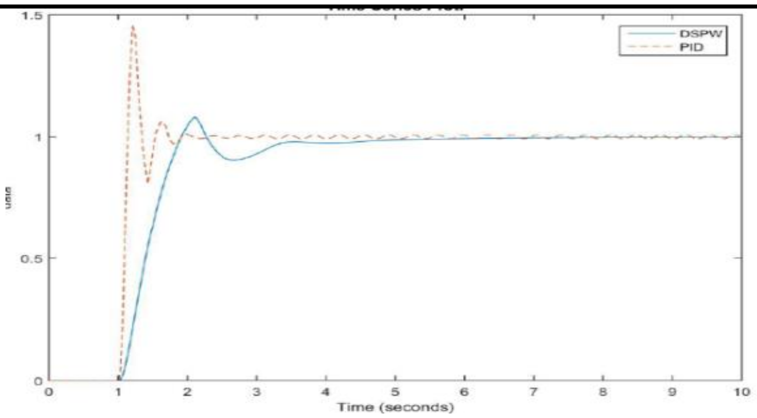
1. Discretize the process transfer function; bringing it to a simpler form, so as to make it easy to mould the system output as needed.
2. Use this discretized function to build a microcontroller based system, making it a viable method of control.

The effect of change of slope a, in output can be noted by seeing it in operation. For this transfer function $G_p(s)$ is used where,

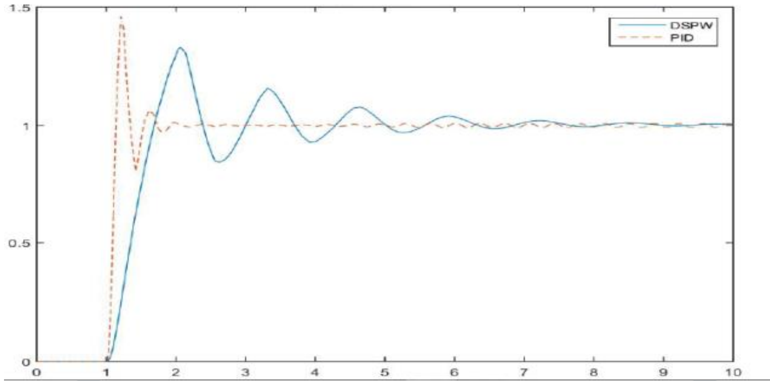
$$G_p(s) = \frac{19.9\, e^{-.01s}}{s(0.09s + 1)}$$

The parameters used for controller being:

	K_p	L	T_i	T_D	T_s
48	.0539	1.068	2.136	.534	.01



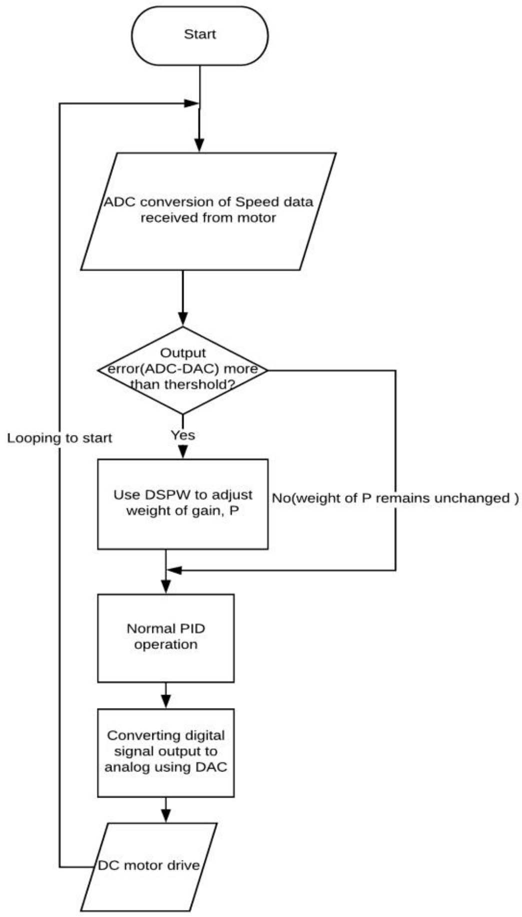
For, slope a= 1



For, slope a= 4

So the difference can be clearly seen, so it is advisable that selection of this factor is done based on the process to be controlled. Here the genetic algorithm comes in to play, where use of it prior to code loading in microprocessor will help us find a good value for any given process. It is to be noted that this is done using MATLAB.

So, discretization of the process and ideal slope(a) value is found based the process details. Following which the controller unit is programmed where the code follows the shown flowchart's steps:



The flowchart has simplified the stages of PID, ADC and DAC as the main focus here remains the DSPW β_f; and also operation of these stages are well known.

The microcontroller unit used being STM32f407-DISCOVERY with LABVIEW used for real time monitoring the result thus obtained is shown below:

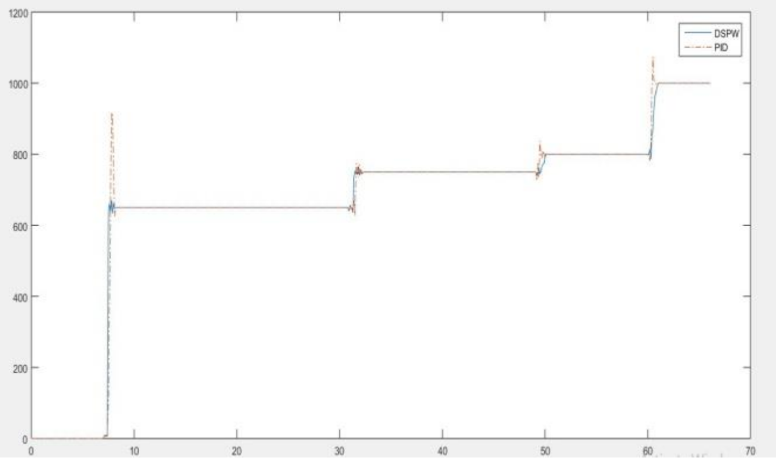


Fig 3: Embedded PID v/s DSPW PID

The plot was made using MATLAB based on the data obtained by the LABVIEW, the system controlled being a DC motor unit. The values of the PID parameters were derived using process curve method (step response method), which resulted in the values being $K_p = 1.5$,$T_i = .1, T_d = .025$ this derived with the sampling time being .1s. The plot is a time v/s speed (rpm) plot of the PID and DSPW PID at the speed of 650,750,800 & 1000 rpm.

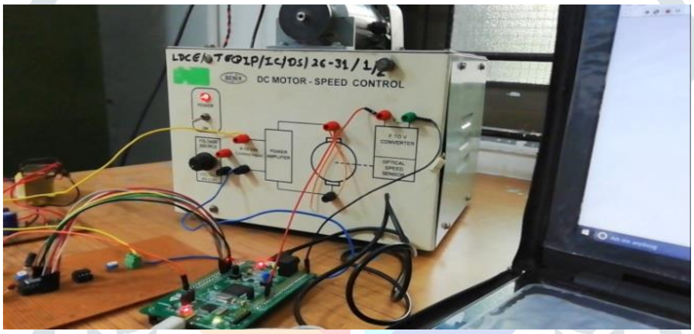


Image of the unit controlled using the controller

III. CONCLUSION:

Thus, this paper proposes a method of practical implementation of Digital control techniques. The proposed method can be further improved by the introduction of a companion program that would not only, customize the parameters for the process but will also transmit those changes to the controller; making the system simple to use and tune.

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