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A Novel technique for the Control of Processes with long dead time by Smith Predictor using Gravitational Search Algorithm

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***Abstract**: The Modified Smith Predictor(MSP) is also known as Dead-Time Compensator for the integrating processes. In this paper the MSP is a PID controller in series with a second order filter which is defined by an adjustable parameter and dead-time. Optimization of the regulatory performance of this controller is performed by Gravitational Search Algorithm. Excellent performance/robustness is obtained for stable, integrating and unstable processes including dead-time which is confirmed by simulations.*

1. Introduction

In the process industries, the occurrence of "dead time" or "transportation lag" is quite common. For the majority of simple control loops, the amount of dead time is usually not significant when compared to the time constant. For more complicated control loops like those for quality control, dead time can be very significant and may even be longer than the system time constant. The reasons for this may include analysis delay and the down-stream location of the sampling point for the quality analyser. Another class of examples is characterized by a multitude of small lags, such as a long bank of heat exchangers, or a distillation column with many trays, giving rise to what is called "apparent" dead time. Dead-Time Compensator (DTC) is proposed for improved control of unstable delay processes [1]. In comparison to the Modified Smith Predictor (MSP) [2,3], presented Fig. 1, the control system of [1] has such a structure that the gain $K_r = 1$, $F_o(s) = k_{d3}(1 + T_{d3}s)$, $G_{f1}(s) = k_{d1}(1 + T_{d1}s)$, $G_{f2}(s) = k_{d2}(1 + T_{d2}s)$, the reference r(t) is multiplied by a gain k_4 and $G_{mo}(s)$ is the dead- time free part of the corresponding unstable model. The MSP in Fig. 1 is a straightforward modification of the Smith Predictor (SP) [4]: PI controller in SP [5] is replaced with the gain Kr and the estimated value of the disturbance dˆ is introduced in the loop to eliminate the effect of the load step disturbance d, for processes with integral action. Estimated value dˆ is obtained from the PD controller Fo(s). There are five adjustable parameters Kr, Ko, Kp, To and Tf, for a given value of the dead-time . Robust tuning of the MSP is considered in [6,7].In the comparative analysis of regulatory performance of DTC's and PID controllers in [8], the Smith Predictor [4] is used as a representative DTC for stable processes, while the MSP [2,3] is used as a representative DTC for integrating processes, as in the interactive tool for analysis of time-delay systems [9], where DTC from [1] is used as a representative for unstable processes. however in Section 2 it is shown that MSP is a PID controller in series with a second-order filter, defined by the dead-time and an adjustable parameter. In section 3 there is an introduction about the GSA. Experimental results are presented in section 4.

2. A new interpretation and implementation of the MSP controller

Rejection of the load step disturbance is of primary importance to evaluate controller performance under constraints on the robustness [14]. For r = 0 in Fig. 1, it follows that the MSP controller is defined by:

$$U(s) = -C(s,\ q)\ Y(s), \quad (1)$$

$$C(s,q) = \gamma \frac{k_d s^2 + ks + ki}{s(T_f s+1)} Fc(s) \quad , \quad (2)$$

$$F_C(s) = \frac{1}{1+(K_r K_p / s)(1-e^{-\tau s})} \quad (3)$$

$$k_i = K_o K_r K_p \quad k = k_i T_o + K_o + K_r$$
$$k_d = K_o T_o + K_r T_f \quad (4)$$

from (1) and (2) one obtains that the MSP controller C(s,q) is a PID controller in series with a filter FC(s). An effective implementation of the MSP controller C(s,q), denoted as the MSP-PID controller, is given by:

$$U(s) = \gamma(k(bR(s) - Y_f(s)) + \frac{k_i}{s}(R(s) - Y_f(s)) - k_d sY_f(s))F_C(s), 0 \le b \tag{5}$$

$$Y_f(s) = F_n(s)Y(s), \quad F_n(s) = \frac{1}{T_f s + 1} \tag{6}$$

The MSP controller C(s,q) can be interpreted as an extension of the standard two-degree of-freedom PID controller. Namely, for FC (s) = 1 relations (5) and (6) define a two-degree-of-freedom PID controller implementation used in [10,15].

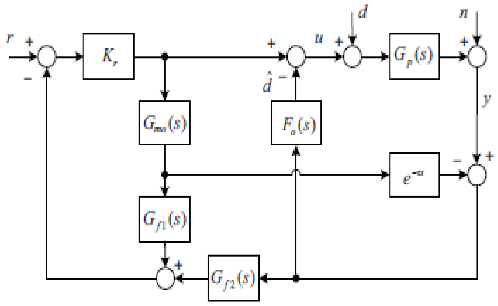


Fig-1

3. Gravitational Search Algorithm

The gravitational search algorithm (GSA) is one of the newest stochastic search algorithm developed by Rashedi et al. [11]. This algorithm, which is based on Newtonian laws of gravity and mass interaction, has a great potential to be a break-through optimization method. In this algorithm, agents are taken into consideration as objects and their performances are measured by their masses. Every object represents a solution or a part of a solution to the problem. All these objects attract each other by the gravity force,

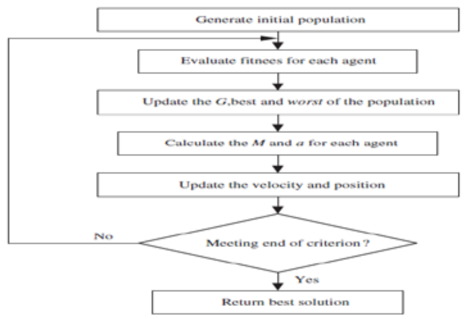


Fig.2- The flow chart of the GSA.

and this force causes a global movement of all objects towards the objects with heavier masses. Due to the heavier masses have higher fitness values; they describe good optimal solution to the problem and they move slowly than lighter ones representing worse solutions. In GSA, each mass has four particulars: its position, its inertial mass (M_{ii}), its active gravitational mass (M_{ai}) and passive gravitational mass (M_{pi}). The position of the mass equaled to a solution of the problem and its gravitational and inertial masses are specified using a fitness function [30–32].

At the beginning of the algorithm the position of a system are described with N (dimension of the search space) masses

$$X_i = (x_i^1 \ldots x_i^d \ldots x_i^n) \quad \text{for i = 1,2,3……,N,} \tag{7}$$

where n is the space dimension of the problem and x^d_i defines the position of the ith agent in the dth dimension. Initially, the agents of the solution are defined randomly and according to Newton gravitation theory, a gravitational force from mass j acts mass i at the time t is specified as follows:

$$F_{ij}^d(t) = G(t)\frac{M_i(t) * M_j(t)}{R_{ij}(t) + \varepsilon}(x_j^d(t) - x_i^d(t)) \tag{8}$$

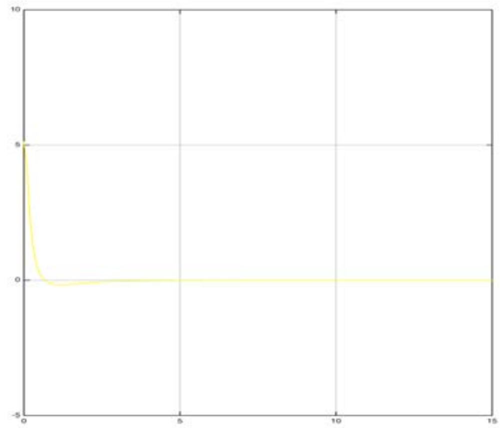
The next position and next velocity of an agent can be computed as follows:

$$v_i^d(t+1) = rand_i * v_i^d(t) + a_i^d(t) \quad , \tag{9}$$

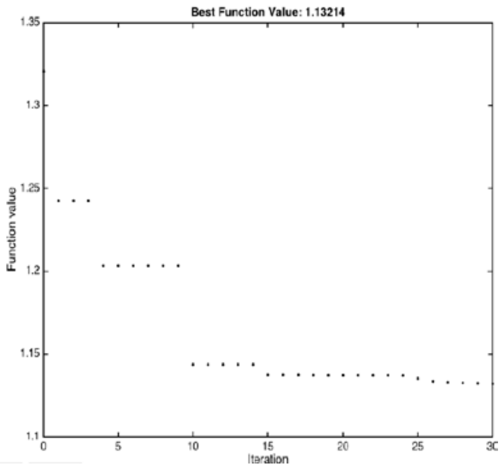
$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1) \quad , \tag{10}$$

4. Simulation and Analysis

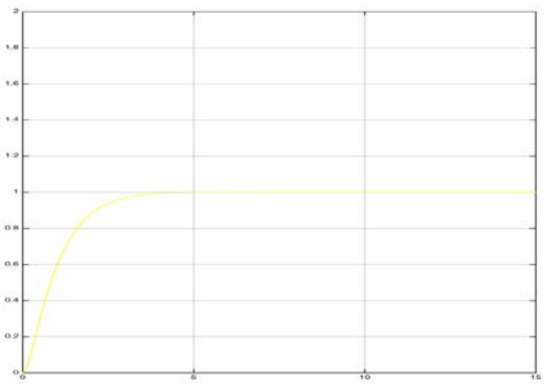
Gravitational search algorithm (GSA) self-tuning PI Smith prediction controller is designed by MATLAB software, emulation experiments is done to compare the control performance of this controller and traditional PI Smith prediction controller. The mathematic model of control object is established based on a monitor AGC system for hot rolling mill, and the model parameters are: material plastic coefficient Q =3000kN/mm; mill stiffness M =3500kN/mm; rolling speed v =10m/s; distance between roll gap and gauge meter Lg =3500mm. The emulation curve is shown in Fig. A step of 20μm changing is given to reference thickness. The result shows that GSA self-tuning PI Smith prediction controller has faster response speed smaller overshoot than traditional PID Smith prediction controller.



(a)



(b)



(c)

Fig3: (a) amplitude vs time (b) function value vs iteration (c) amplitude vs time.

5. Conclusions

The GSA control strategy was brought in normal PI Smith prediction controller to obtain optimal parameter. The explicit expression of GSA self-tuning PI Smith prediction controller was derived which provide theory basis for field application. The simulation results indicate that the control performance of the GSA self-tuning PI Smith prediction controller is better than the traditional PID Smith prediction controller

6. References

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