# Design of an Optimized Intelligent Controller of Electromechanical System in Aerospace Application


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***Abstract*-The objective of condition based maintenance (CBM) is typically to determine an optimal maintenance policy to minimize the overall maintenance cost based on condition monitoring information. In Aircraft operator and the maintenance people starving to reduce the cost of aircraft maintenance. So the condition based monitoring for electromechanical control valve is very popular recently. This paper has been proposed an optimized Fractional order Proportional-integral-derivative (FOPID) controller for electromechanical actuated worm gear operated fuel shut off valve.**



***Keywords: Computational Intelligence; electromechanical System Maintenance; Differential Evolution; Proportional Integral and Derivative control; Fractional Control, CBM.***


## I. INTRODUCTION

For Aerospace system Condition Based Maintenance (CBM) is much different than the other industrial system, civil and electro-mechanical maintenance system. In Aerospace application the major issues are size, weight and airworthy certification of any component. It also have to consider certification of aviation and high level safety critical issue. CBM is gaining importance in industry because of the need to increase machine availability. Even In recent years, several diagnostic and prognostic models based on statistical, artificial intelligence (AI) and soft computing (SC) techniques have been proposed [1-4] and getting the satisfactory results. In this work we apply the DE to optimize the control parameter to reducing the mechanical friction of the worm gear and reducing the fault occurrence due to friction in the electromechanical control ball -valve. In [5] presented combining with Particle swam optimization (PSO) [9] other computational intelligence (CI) techniques like ANN and SVM for automated selection of features and detection of machinery fault.

Fractional order dynamic systems and controllers, is based on fractional order calculus [6]. Fractional calculus is a branch of mathematical analysis that studies the possibility of taking real number power of the differential operator and integration operator. From a purely mathematical point of view there are several ways to define fractional order derivatives and integrals. The generalized different integrator operator may be put forward as:

$$ {}_aD_t^q f(t) = \frac{d^q f(t)}{[d(t-a)]^q} \tag{1}$$

Where $q$ represents the real order of the different integral (an $n$ is used in some literature to denote an integer order), t is the parameter for which the different integral is taken, and $a$ is the lower limit. Unless otherwise stated the lower limit will be *0* and left out of the notation. Caputo used a popular definition used to compute different integral in 1960s. The definition for Caputo's fractional derivative of order $\lambda$ with respect to the variable $t$ and with the starting point $t = 0$ goes as follows [20, 21],

$$ {}_0D_t^\lambda y(t) = \frac{1}{\Gamma(1-\delta)} \int_0^t \frac{y^{(m+1)}(\tau)d\tau}{(t-\tau)^\delta}, $$

$$ \gamma = m+\delta, m \in Z, 0<\delta \le 1) \tag{2}$$

Here, $\Gamma(z)$ is Euler's Gamma function. If $\gamma < 0$, then we have a fractional integral of order $-\gamma$ given as:

$$ {}_0I_t^{-\gamma} y(t) = {}_0D_t^\gamma y(t) = \frac{1}{\Gamma(-\gamma)} \int_0^t \frac{y(\tau)d\tau}{(t-\tau)^{1+\gamma}}, (\gamma<0) \tag{3}$$

One distinct advantage of using the Caputo's definition is that it only allows for consideration of easily interpretable initial conditions but it is also bounded, which means the derivative of a constant is equal to zero. In time domain, a fractional order system is governed by an *n*-term inhomogeneous fractional order differential equation (FDE):

$$ a_n D^{\beta_n} y(t) + a_{n-1} D^{\beta_{n-1}} y(t) + a_1 D^{\beta_1} y(t) + a_0 D^{\beta_0} y(t) = u(t) \tag{4}$$

Where $D^\lambda \equiv {}_0D_t^\lambda$ is the Caputo's fractional derivative of order $\lambda$. Converting to frequency domain, the fractional order transfer function of such a system may be obtained through the Laplace transform function as follows,

$$G_n(s)=\frac{1}{a_n s^{\beta_n}+a_{n-1}s^{\beta_{n-1}}+..........+a_1 s^{\beta_1}+a_0 s^{\beta_0}} \quad (5)$$

Where, $\beta_k\,(k=0,1,.......,n)$ is an arbitrary real number, $\beta_n > \beta_{n-1} > ......... > \beta_1 > \beta_0 > 0$ and $a_k\,(k=0,1,.......,n)$ is an arbitrary constant. Finally we would like to mention here that the Laplace transform of the fractional derivative might be given as,

$$\int_0^{\infty} e^{-st} D^{\gamma} y(t)dt = s^{\gamma} Y(s) - \sum_{k=0}^{m} s^{\gamma-k-1} y^{(k)}(\theta) \quad (6)$$

For, $\gamma < 0$ (i.e., for the case of a fractional integral) the sum in the right hand side must be omitted.

In [7] it was advocated that fractional order calculus would play a major role in an intelligent mechatronic system. In conventional gears has more friction but worm gears is pure sliding and these attractive features desirable in Aerospace application. Worm gears are frequently used in electro-mechanical systems. The friction plays a dominant role in the performance of the worm gear system [8] In FOPID controller *I* and *D* operations are usually of fractional order, therefore besides setting the proportional, derivative and integral constants $K_p, T_d, T_i$ we have two more parameters: the order of fractional integration $\lambda$ and that of fractional derivative $\mu$. Finding an optimal set of values for $K_p, T_i, T_d, \lambda,$ and $\mu$ to meet the user specifications for a given plant (worm gear teeth friction minimization control) parameter in multi-dimensional hyperspace. The design method focuses on optimum placing of the dominant closed loop poles and incorporates the constraints thus obtained using DE algorithm. The optimization-based design process has been tested for actuating the response of four process plants of which two are of integer order and two are of fractional order. The performance of the DE based $PI^{\lambda}D^{\mu}$ controller has been compared with GA. GAs have been used to make the classification process faster and accurate using the minimum number of features which primarily characterize the system conditions with optimized structure or parameters of ANNs and SVMs [10].

## II. PROBLEM DESCRIPTION

In control engineering it is interest to design or model a mechanical friction. The interest to design and control strategies is because it alleviates the performance of the system. If a good friction model available then the performance of the system being increase, which can improve the maintenance cost and reduced the fault occurrence in the critical system such as electromechanical actuator in aerospace application, process control valve, and robotics. The predictive motion control scheme [11] has been proposed earlier in this system we don't consider the friction in nonlinear analysis. In this paper we introduced the friction and try to reduce the BLDC motor torque by reducing the friction. PID controllers have been used for several decades in industries for control applications. The reason for their wide popularity lies in the simplicity of design and good performance including low percentage overshoot and small settling time for slow response system like electromechanical system [12]. The most common form of non-integer model is $PI^{\lambda}D^{\mu}$ controller. $\lambda$ Is the order of the integrator and, $\mu$ is the order of differentiator. The transfer functions of such a controller written as:

$$c(s)=K_p+\frac{K_i}{s^{\lambda}}+K_d s^{\mu} \quad (7)$$

Or in time domain controllers output written as:

$$u(t)=K_p e(t)+K_i D^{-\lambda}e(t)+K_d D^{\mu}e(t) \quad (8)$$

With different values of the parameter and the estimated structure of the controller is such that:

For, $\lambda=1, \mu=1$ a classical PID controller

$$c(s)=K_p+\frac{K_i}{s}+K_d s \quad (9)$$

For, $K_d=0, \lambda=1$ a classical PI controller

$$c(s)=K_p+\frac{K_i}{s} \quad (10)$$

For, $K_d=0$ a non-integer $PI^{\lambda}$ controller

$$c(s)=K_p+\frac{K_i}{s^{\lambda}} \quad (11)$$

Non-integer or Fractional $PI^{\lambda}D^{\mu}$ controller has the most important advantage lies in the fact that these types of controllers are less sensitive to change of parameters of a controlled system. This is due to the extra degrees of freedom to better adjust the dynamical properties of a non-integer order control system. In [13].Differential Evolution (DE) [14, 15] has recently become quite popular as a simple and efficient scheme for global optimization over continuous spaces. It has reportedly outperformed many types of evolutionary algorithms and search heuristics like PSO when tested over both benchmarks and real world problems [16]. In this work, a state-of-the-art version of DE has been used for finding the optimal values of gear friction minimization so that the controller chooses its best optimal values. In this paper we design the controller and test it in the fuel valve control scheme and simulation shows that this controller gives better performance in practical system also. Even in [17] the results has been shown we also compare with that also still our system gives more accurate control for this specific application. The schematic diagram of the controller and the gear system with as shown in figure 1.The plant and the controller function has been listed in table 1. Since the controller design is model-based approaches so including high frequencies is essential for design a robust nonlinear controller. Electromechanical actuated hydraulic systems are essentially nonlinear. So the dynamic behavior of the system and tracking performance still has to analyze and that is the next level of the work.

TABLE 1. TRANSFER FUNCTIONS OF PID CONTROLLER

| Process Plant Transfer Function $G_p(s)$ | Controller Transfer Function $G_c(s)$ |
| --- | --- |
| $\frac{s^2}{50s+400}$ | $0.350+20.287s^{-0.1}+1.009s^{0.29}$ |
| $\frac{1}{0.8s^{2.2}+0.5s^{0.9}+1}$ | $20+1.35s^{-0.82}+12s^{0.83}$ |

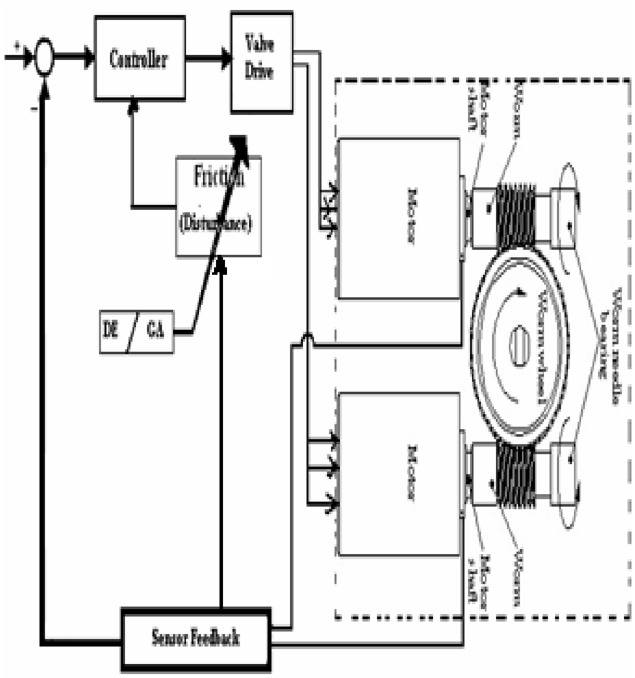

Fig. 1. Schematic configuration of the proposed controller coupled with electromechanical gear

## III. EXPERIMENTAL RESULTS AND DISCUSSIONS

The Fractional order system with optimized controller for the first time to control worm gear friction is applied in this paper. These innovative predictive maintenance solutions, utilizing condition-monitoring systems are currently under testing in order to support the introduction of new electrically actuated aircraft fuel control valve systems to provide reliability assurances. An embedded intelligent CBM and control method has been introduced in this paper. This would allow pre flight warning that can help to reducing fault. Controlling the friction by fractional order PID (FOPID) controllers based on the DE is presented in this paper. Fractional calculus can provide novel and higher performance extension for FOPID controllers. The obtained results give experimental evidence of the capability of the algorithm and the proposed model. The experimental results are a significant contribution of this work and have been obtained through the development of a suitable software solution that allows interfacing the optimization algorithm with the sensors and the actuator. The all experiment and the test of the system have been done in laboratory and the control parameter settings done by experimental testing.

The data acquisition and the simulation we use standard PC with XP, Core 2 Duo Processor, 1Gb RAM, and the LabVIEW software of National Instrument and there data acquisition system. We use FOPID control, for this complex advanced control with multiple inputs and outputs. Following the same fundamental principles, we use our computer and data acquisition hardware to take sensor measurements, compare the measured values with the desired set points in software, and update output signals accordingly. There are a number of advantages to using a Industrial PC for control applications that lead to flexibility, high performance, and customization. The simulation has carried out in MATLAB 2010 platform coupling with LabVIEW software.

Figure 2 shows that the controller response after optimized parameter DE in the system and Figure 3 illustrate the comparative simulation results with GA, and proposed DE.

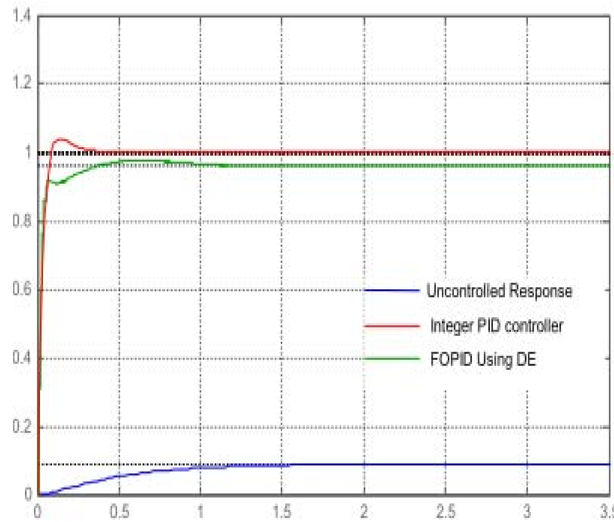

Fig. 2. Controller output response with optimized DE

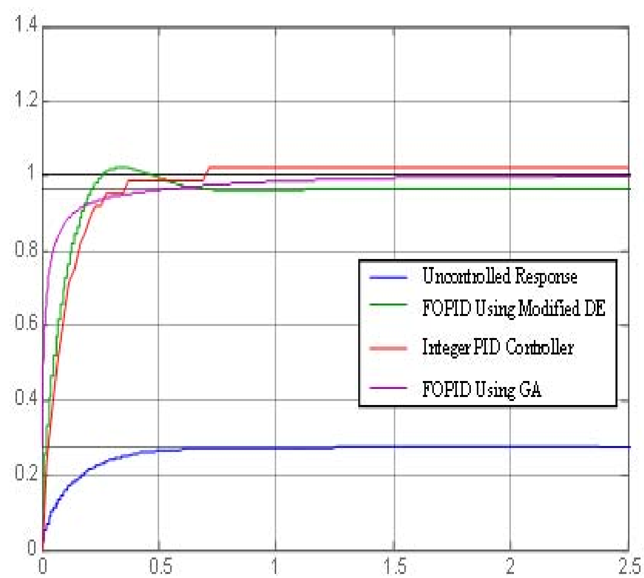

Fig. 3. Controller output response comparison with optimized DE and GA

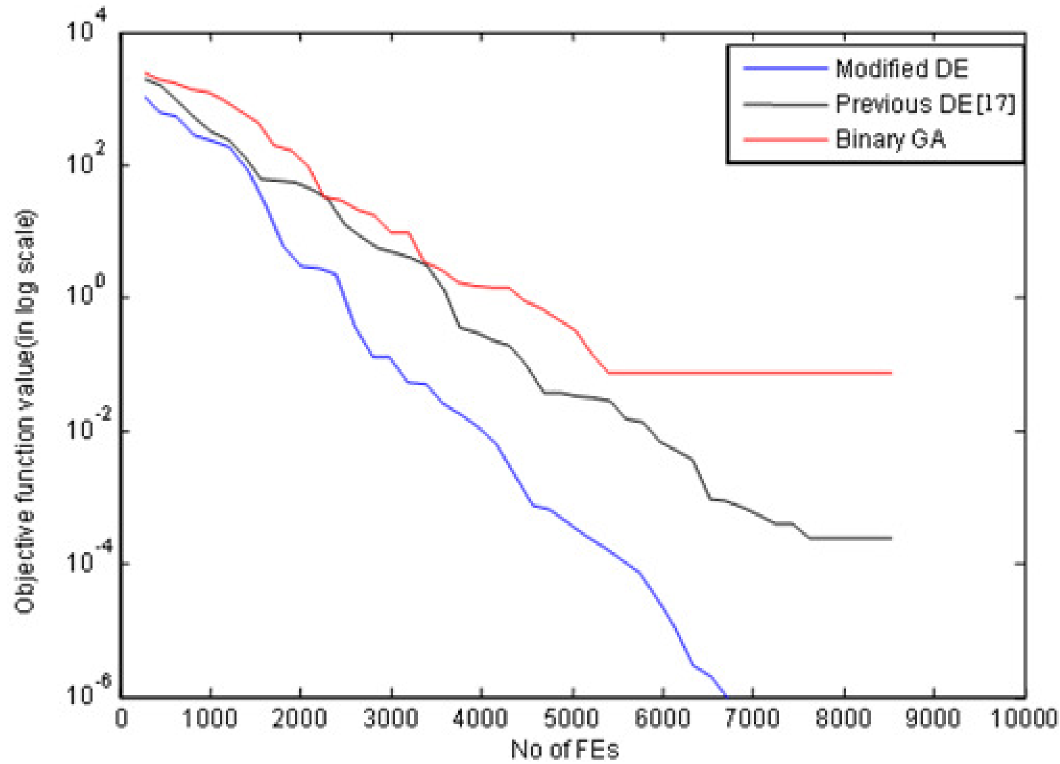


Fig. 4.Comparation results with modified DE, DE and GA

TABLE 2. PERFORMANCE SUMMARY OF CLOSED LOOP SYSTEM UNDER DIFFERENT PID CONTROLLERS AGAINST THE UNIT STEP FUNCTION

| Gear Friction Type | Type of Controllers Used | System Step Response Observed | | | Final Objective function values obtained |
|---|---|---|---|---|---|
| | | Maximum Overshoot (%) ± Standard Deviation (%) | Rise Time (Sec) ± Standard Deviation (Sec) | Steady State Error (%) ± Standard Deviation (%) | |
| 1. | Optimized Fractional Controller using DE | **2.11 ± (0.31)** | **0.205 ±(0.051)** | **2.5 ±(0.010)** | **0.00 ±(0.0000)** |
| | Integer PID controller using DE | 3.23 ± (0.34) | 0.201 ±(0.007) | 0.1 ±(0.001) | 0.00 ±(0.0000) |
| | Fractional Controller using GA | 5.31 ± (0.87) | 0.505 ±(0.088) | 2.1 ±(0.056) | 0.0212 ±(0.0025) |
| 2. | Optimized Fractional Controller using DE | **1.93 ±(0.089)** | **0.218 ±(0.015)** | **1.6 ±(0.034)** | **0.00 ±(0.0000)** |
| | Integer PID controller using DE | 0.21 ±(0.011) | 0.435 ±(0.078) | 0.2 ±(0.010) | 0.00 ±(0.0000) |
| | Fractional Controller using GA | 0.27 ± (0.017) | 1.312 ±(0.313) | 0.3 ±(0.013) | 0.0522 ±(0.0037) |

How the objective function value decreases with the number of Function Evaluations (FEs) is illustrated in Figure 4. The graphs indicate that the DE based method could find better solutions consuming lesser amount of computational time.

## IV. CONCLUSIONS

In this paper presents a new optimized controller tuning methods. A new hybrid control methods applied to ensure precise control into electromechanical on-off valve actuation. The advantage of the proposed system is show finally, by the results of evidence that the use of a detailed and validated model of the system can produce a complete process of good performance.

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