Preface

Mathematical analysis of operational system results in a large scale representation demanding a rigorous study. The necessity is fulfilled by the precise mathematics motivating towards the fractional calculus. Thus, fractional calculus is of great importance for accurate and complete study and analysis of any system or structure. In addition, many physical phenomena bear “intrinsic” fractional order interpretation demanding an illumination from the fractional order calculus. History of fractional calculus is dated around 300 years old but due to having tough mathematics and unavailability of efficient and suitable toolbox it was untouched. From last few decades its non-integer characteristics has atracted the focus of researchers and now it is being extensively exercised for fractional modelling and control. Advantage of fractional control theory is the involvement of both engineering and mathematics to achieve the desired performance for a set of specifications. Significantly, Fractional order control is the application of fractional calculus producing more accurate result than the conventional one.

A variety of fractional order controllers are practiced in the literature for getting desired response from a specific class of system. Extensively accepted among the controllers is the Fractional order proportional, integral and derivative (FOPID) controller, symbolised as $PI^{\lambda}D^{\mu}$. FOPID controller is the universal form of the conventional PID controller offering two extra tuning lumps, the fractional power of integral control (λ) and derivative control(μ). These additional degrees of freedoms are the supreme inspiration for the researchers to propose excellent controller for any system. The most complicated assignment for designing the FOPID controller is to locate the appropriate value of the all five controller parameters (i.e. $K_P, K_I, K_D, \lambda, \text{and } \mu$) simultaneously, for which various rule-based, analytical and numerical tuning techniques are available. Several toolbars like CRONE, NINTEGER, and FOMCON, etc. are also available for design and implementation of fractional order controllers.

A simple rule based optimization technique known as Nelder and Mead algorithm (NM-Algorithm) was introduced by Nelder and Mead in 1965. It minimizes a nonlinear function of *n* variables by applying a process of pattern search without having any derivative information about the variables. The technique has been used for optimization of many engineering problems including design of conventional PID controller but it has never been practiced for optimization of FOPID controller parameters. This motivates for usage of this technique to optimize the parameters of FOPID controller.

Further, the estimation of variables through Swarm Intelligence (SI) based techniques under numerical tuning methodologies is extensively available in the literature. These techniques are inspired by hunting and searching strategy of a particular species present in nature. As per author's cram and analysis, none of the SI techniques imitate the leadership quality as of hierarchy of grey wolves for optimization of FOPID controller parameters. Reason for its acceptability is the efficient hunting strategy in packs. This technique is a recent meta-heuristic technique known as Grey Wolf Optimizer (GWO). This motivates to implement the social behaviour of grey wolves for finding the optimum value of the parameters of the FOPID controller.

Lastly, a Modified Grey Wolf Optimizer (MGWO) is presented for optimization of FOPID controller parameters. Moreover, a novel fitness function is defined for optimization using MGWO technique. This fitness function is represented in terms of rise-time (*RT*), settling-time (*ST*), peak-overshoot (*MP*), Gain-Margin (*GM*), Phase-

Margin (*PM*), integral time weighted absolute error (*ITAE*) and integral time weighted square error (*ITSE*).

Thus, this thesis proposes the research of fractional calculus in the context to the design of fractional order PI and PID controller and their parameter optimization using three different techniques namely NM-algorithm, GWO and MGWO. The introductory part of the thesis presents a brief theoretical background, preliminaries and definitions of fractional calculus, desired for designing the fractional order controller. The introduction is followed by the illustration about the applications of fractional calculus and fractional order control. Latter part of this thesis describes the three different optimization algorithms implemented for optimization of FOPID controller parameters for different type of systems like magnetic levitation system, non-monotonic phase system, Non-minimum Phase System with Time Delay; second order System with Time Delay, second order linear system, automatic voltage regulator (AVR) system, and Spherical Tank System.

The performance of the proposed optimization algorithms for optimization of FOPID controller parameters is validated with existing FOPID as well as classical PID controllers in the literature. All the work is performed with FOMCON toolbox in MATLAB environment.

The thesis is further organized as follows: **Chapter 1** establish a brief review of literature offering the motivation of this work. It also gives an insight into the organization of the work carried out in the thesis. **Chapter 2** contributes the necessary preliminaries required for this work. In addition, stability of the Fractional Order System, Approximation of Fractional Order Operators, and an overview of FOMCON Toolbox are also discussed. Moreover, this chapter also enlighten the fractional order controller, it's different forms and advantages of using fractional order controllers. In **Chapter 3** presents a brief description about the Nelder's and Mead Optimization algorithm and optimization of FOPID controller parameters is also performed using NM-algorithm for a variety of system. **Chapter 4** discusses the detail strategy and operation GWO technique. The optimization of FOPID controller parameter is performed using this technique for same systems practiced in the previous chapter. In **Chapter 5** a modified version of GWO algorithm (i.e. MGWO) is presented. Further, parameters of FOPID controller are optimized using MGWO for the same systems practiced in chapter 3. In **Chapter 6** Comparison and Analysis of all Proposed Algorithms is performed for various drilled problems. **Chapter 7** concludes the work carried out and highlights the future scope.