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A SOFT COMPUTING APPROACH ON SHIP TRAJECTORY CONTROL FOR MARINE APPLICATIONS

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ABSTRACT

The objective of this paper is to create a PID controller for the movement of the cargo ship containing with oil that is tuned using soft computing algorithms. Oscillation in liquids is called 'slosh' or 'slop' and is important because the movement of large quantities of liquid can strongly influence the movement of the container itself – this is usually undesirable and often dangerous. The liquid slosh system is notoriously difficult to control optimally using a PID controller because the system parameters are constantly changing. The movement of the cargo ship containing with oil is a complex nonlinear system. Due to its strong nonlinear behavior, the problem of identification and control of cargo ship filled with oil is always a challenging task. Usually the cargo ship filled with oil is controlled using linear PID control configurations. If the process is subjected to larger disturbance due to liquid slosh effect, the state cargo ship can considerably deviate from the aforementioned neighborhood and consequently deteriorates the performance of the controller. They are inherently nonlinear. In spite of the knowledge that one of the characteristic is inherent nonlinearity of the process, it is traditionally controlled using linear control design techniques. The ability of PID controllers to compensate most practical industrial processes has led to their wide acceptance in industrial applications. To aid with the development of this system was chosen at random and a PID controller was designed for it using conventional methods. A genetic algorithm was then created to evaluate the PID coefficients of the same system and the results of the two techniques were compared. A fourth order system was selected as the Ball and Hoop system.

Keywords: cargo ship, PID controller, genetic algorithm, non linear system.

INTRODUCTION

In most of the industrial applications use PID controllers because it is simple, flexible and robust. Proportional + Integral + Derivative (PID) controllers are widely used in various industrial applications in which set point tracking and disturbance rejection are necessary. This controller provides an optimal and robust performance for a wide range of operating conditions for stable, unstable and nonlinear processes. A PID controller directly operates on the error signal and this may produce a large overshoot in the process due to proportional and derivative kick. Therefore proper tuning of PID parameters becomes very important for a nonlinear Process. A properly adjusted controller gives excellent regulation of the measured variable, if poorly adjusted the controller can destabilize the system causing fluctuations, therefore the tuning of a controller becomes an important step in controlling of any loop. The control system becomes poor in characteristics and even becomes unstable, if improper values of the controller tuning constants are used. So it becomes necessary to tune the controller parameters to achieve good control performance with proper choice of tuning constant.

The conventional methods can't be used for complex processes such as the missile with liquid fuel system, slosh of aviation fuel in an aircraft, liquid load in a railway wagon tanker, movement of the fuel load in a Formula 1 car and for economical and/or safety reasons, these process loops to be operated in unstable steady state are unstable. Therefore the engineers have constantly been in search for automatic tuning methods and have come up with various solutions such as genetic algorithm.

SYSTEM MODELING

A cargo ship containing with oil resembles a Ball and Hoop System. The ball and hoop apparatus consists of a steel ball that is free to roll on the inside of a rotating circular hoop. This system illustrates the complex dynamics of liquid slosh i.e. the way liquid behaves in a moving container. The ball and hoop apparatus is difficult to control optimally using a PID controller because the system parameters are constantly changing.

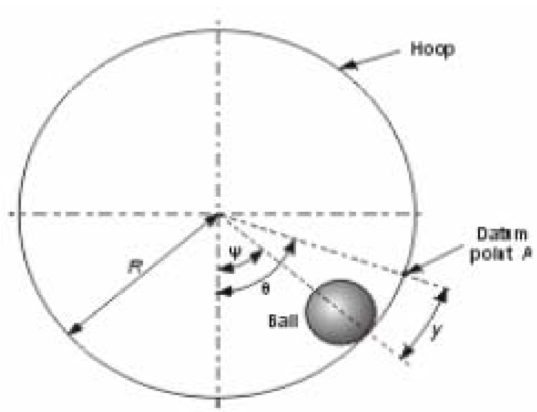

Figure-1. Ball and Hoop Model.

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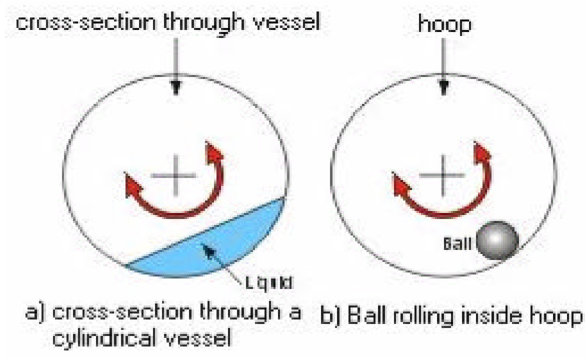

Figure-2. Liquid Slosh effect – Ball and Hoop model analogy.

The Ball and Hoop System illustrate the dynamics of a steel ball that is free to roll on the inside of a rotating circular hoop. There is a groove on the inside edge of the hoop so that a steel ball can roll freely inside the hoop. This introduces the complexity of the rolling radius of the ball being different to the actual radius of the ball as illustrated in Figure-1.

PID CONTROLLER

PID stands for Proportional (P), Integral (I) and Derivative (D). The PID controller produces a control signal consisting of three terms

1. Proportional to error signal
2. Proportional to integral error signal
3. Proportional to derivative error signal

PID control is a type of feed back controller, whose output is a Control Variable (CV), is generally based on the error (e) between user defined set point (SP) and measured Process Variable (PV). Each element of the PID controller refers to a particular action taken on the error.

Proportional

The error is multiplied by a gain K_p. This is an adjust amplifier. In many systems K_p is responsible for process stability. If K_p is too low, then PV can drift away. If K_p is too high then process variable can oscillate.

Integral

The integral of error is multiplied by a gain K_i. In many systems K_i is responsible for driving error to zero, but to set K_i too high is to invite oscillation (or) instability (or) integrator windup (or) actuator saturation.

Derivative

The rate of change of error signal is multiplied by a gain, K_d. In many systems K_d is responsible for system response. If K_d is too high then PV will oscillate. If K_d is too low, then PV will oscillate. If K_d is too low, then PV will respond sluggishly. The designer should also note that derivative action amplifies any noise in the error signal.

Three-mode PID controller

The general equation of PID controller is

$$U(t) = K_pe(t) + 1/Ti \int e(t)\, dt + T_d * de(t)/dt + P_0$$

Where,
K_p = proportional gain
Ti = integral time
T_d= derivative time

The variable e(t) represents the tracking error which is the difference between the desired input value and the actual output. This error signal will be sent to the PID controller and the controller computes both the derivative and the integral of this error signal. The signal u(t) just past the controller is now equal to the proportional gain (K_p) times the magnitude of the error plus the integral gain (K_i) times the integral of the error plus the derivative gain (K_d) times the derivative of the error.

METHODS FOR PID CONTROLLER TUNING

The PID control algorithm is used for the control of almost all loops in the process industries, and is also the basis for many advanced control algorithms and strategies. In order to be able to use a controller, it must first be tuned to the system. This tuning synchronizes the controller with the controlled variable, thus allowing the process to be kept at its desired operating condition. Standard methods for tuning controllers and criteria for judging the loop tuning have been used for many years.

1. Ziegler-Nichols method.
2. Cohen- coon method.
3. Trial and error method.
4. Continuous cycling method.
5. Relay feed back method.
6. Kappa-Tau tuning method.

From the above mentioned methods, Ziegler-Nichols Method have been selected, tuned, designed and the results obtained were obtained.

ZIEGLER-NICHOLS METHOD

The earliest known and most popular tuning methodology was proposed by Ziegler and Nichols (ZN) in 1942. They proposed the closed-loop (or ultimate sensitivity) method and the open-loop (or process reaction curve) method. The ZN tuning rules has a serious shortcoming, (i.e) it uses insufficient process information to determine the tuning parameters. This disadvantage leads to poor robust system performance.

The ZN tuning method is based on the determination of processes inherent characteristics such as the process gain (Kp), process time constant (Tp) and process dead time (Lp). This method is based on a registration of the open-loop step response of the system, which is characterized by two parameters. The parameters

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are determined from a unit step response. The point where the slope of the step response has its maximum is determined and tangent at that point is drawn.

The intersections between the tangents and co-ordinate axis give the parameters ‘a’ and ‘L’.

The PID controller parameters are given by,

Kp = 1.2/a
Ti = 2L
Td = L/2
Where
L = Dead time

GENETIC ALGORITHM

Genetic Algorithms (GAs) are a stochastic global search method that mimics the process of natural evolution. It is one of the methods used for optimization. John Holland formally introduced this method in the United States in the 1960 at the University of Michigan. The continuing performance improvement of computational systems has made them attractive for some types of optimization.

The genetic algorithm starts with no knowledge of the correct solution and depends entirely on responses from its environment and evolution operators such as reproduction, crossover and mutation to arrive at the best solution. By starting at several independent points and searching in parallel, the algorithm avoids local minima and converging to sub optimal solutions.

CHARACTERISTICS OF GENETIC ALGORITHM

Genetic Algorithms are search and optimization techniques inspired by two biological principles namely the process of natural selection and the mechanics of natural genetics. GAs manipulates not just one potential solution to a problem but a collection of potential solutions. This is known as population. The potential solution in the population is called chromosomes. These chromosomes are the encoded representations of all the parameters of the solution. Each chromosomes is compared to other chromosomes in the population and awarded fitness rating that indicates how successful this chromosomes to the latter.

To encode better solutions, the GA will use genetic operators or evolution operators such as crossover and mutation for the creation of new chromosomes from the existing ones in the population. This is achieved by either merging the existing ones in the population or by modifying an existing chromosome.

The selection mechanism for parent chromosomes takes the fitness of the parent into account. This will ensure that the better solution will have a higher chance to procreate and donate their beneficial characteristic to their offspring.

A genetic algorithm is typically initialized with a random population consisting of between 20-100 individuals. This population or also known as mating pool is usually represented by a real-valued number or a binary string called a chromosome. For illustrative purposes, the rest of this section represents each chromosome as a binary string. How well an individual performs a task is measured and assessed by the objective function. The objective function assigns each individual a corresponding number called its fitness. The fitness of each chromosome is assessed and a survival of the fittest strategy is applied.

GENETIC ALGORITHMS VERSUS TRADITIONAL METHODS

Genetic algorithms are substantially different to the more traditional search and optimisation techniques. The five main differences are:

1. Genetic algorithms search a population of points in parallel, not from a single point.

2. Genetic algorithms do not require derivative information or other auxiliary knowledge; only the objective function and corresponding fitness levels influence the direction of the search.

3. Genetic algorithms use probabilistic transition rules, not deterministic rules.

4. Genetic algorithms work on an encoding of a parameter set not the parameter set itself (except where real-valued individuals are used).

5. Genetic algorithms may provide a number of potential solutions to a given problem and the choice of the final is left up to the user.

RESULTS AND DISCUSSIONS

MATLAB is packaged as a core program with several “toolboxes”. Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. The conventionally tuned PID and Genetic Algorithm based tuned PID controllers for the derived transfer function example whose response with the Matlab. Let us consider a Ball and Hoop system transfer function example whose response with the conventional PID controller and the response using GA based PID controller is acquired and compared.

A transfer function to validate the ball and hoop process is given below

$$G(s) = \frac{46.21s^2 + 206.1s}{0.9372s^4 + 2.656s^3 + 75.87s^2 + 112.1s}$$

The tuned values through the traditional, as well as the proposed techniques, are analyzed for their responses to a unit step input, with the help of MATLAB simulation and, then, ball and hoop control is presented. A tabulation of the time domain specifications comparison and the performance index comparison for the obtained models with the designed controllers is presented. The classical methods ZN is employed to find out the values of K_p, K_i and K_d. Although the classical method cannot be able to provide the best solution, they give the initial values or boundary values needed to start the soft computing algorithms. Due to the high potential of evolutionary techniques GA is used for finding the optimal solutions, the best values of K_p, K_i and K_d are obtained. From Table-1, it is evident that the GA tuned system gives a better closed loop performance than ZN by achieving error criterion ISE of 1.0013. The closed-loop step response for the different tuning methods is illustrated in Figure-3. The response specifications and performance index for the ball and hoop control loop are given in Table-1. From Figure-3 and Table-1, ZN method yields a system with marginally higher overshoot, longer settling and rise time in comparison to GA method. The closed-loop response for the Z-N method yields higher overshoot and longer settling time. The GA method delivers superior control performance with improved dynamic performance specifications over the other tuning methods.

Table-1. PID Parameters and closed loop response specifications for consistency control.

Tuning method	PID parameters		
	K_p	K_i	K_d
ZN	9.0481	35.0970	0.5831
GA	8.8938	34.4989	0.5732

Tuning method	Dynamic performance specifications			Performance index
	Tr (sec)	Ts (sec)	M p (%)	ISE
ZN	0.04	0.382	19.3	1.0631
GA	0.0101	0.0555	3.15	1.0013

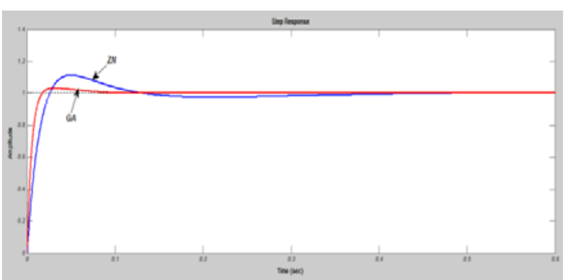

Figure-3. Closed loop transient response of Z-N and soft computing methods.

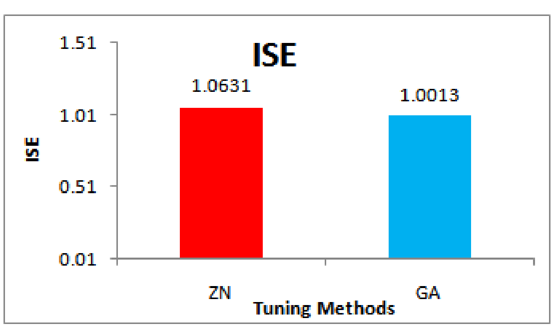

Figure-4. Comparison of error criteria for various tuning methods.

Comparison of error criterion (ISE) for ZN and GA tuning methods of ball and hoop process is illustrated in Figure-4. From the bar chart it is observed that ZN tuned system produces an ISE 1.0631. On the other hand GA tuned system produces ISE of only 1.0013 respectively.

From the above findings, it is observed that soft computing methods produce minimum ISE and also it is evident that the GA tuned system outperforms the ZN systems.

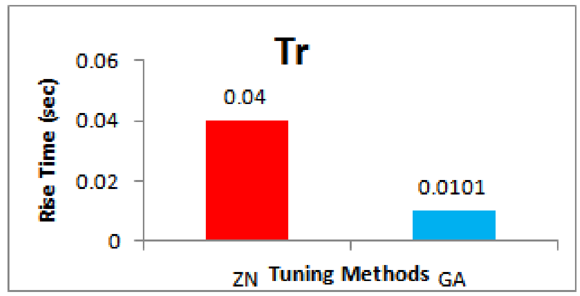

Figure-5. Comparison of rise time for various tuning methods.

Comparison of rise time for GA and ZN tuning methods of ball and hoop process is illustrated in Figure-5. From the bar chart it is observed that ZN tuned system has a rise time of 0.04. The GA tuned system has rise time of 0.0101sec.

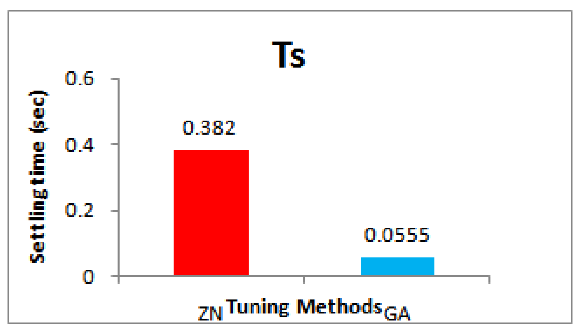

Figure-6. Comparison of settling time for various tuning methods.

Comparison of settling time for ZN and GA methods of ball and hoop process is shown in Figure-6. It shows that ZN tuned controller settles at 0.382 seconds. GA tuned systems settle at 0.0555. It is observed that GA settles at minimum time while comparing with other tuning methods, the GA tuned controller settles much faster settling time of only 0.0555 seconds.

Comparison of overshoot for ZN and GA methods of ball and hoop process is illustrated in Figure-7. From the bar chart it is observed that ZN tuned system produced the overshoot 19.3%. The GA tuned systems have produced the overshoot 3.15. It is observed that GA produce minimum overshoot and also it is evident that GA outperforms the ZN based systems.

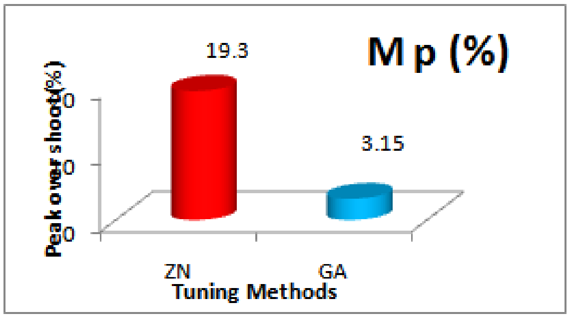

Figure-7. Comparison of overshoot for various tuning methods.

CONCLUSIONS

The mathematical modeling of a cargo ship containing with oil was studied. The PID controller was tuned in order to maintain the pre-determined movement of the cargo ship containing with oil. When there is no control to the process, it generates an inverse response together with an overshoot and considerable delay time. But when the PID control is implemented to the process, the problems of overshoot and delay time are controlled in the ongoing process and are removed considerably but then it was showing instability in terms of rise time and settling time. To overcome this instability in rise time and in settling time a soft computing based PID controller has been used. The GA based control scheme helps to remove those delay times and the inverted response shown in graphs. Rise time and settling time are also reduced. Soft computing methods have proved their excellence in giving better results by improving the steady state characteristics and performance indices. The controller simulation has been done using MATLAB/SIMULINK and the results are compared.

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