Design of Satellite Attitude Control Systems using Adaptive Neural Networks

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Abstract: *This paper investigates the performance of adaptive neural networks through simulations for satellite systems involving three-axis attitude control algorithms. PID tuning is the method employed traditionally. An optimally tuned, to minimizes the deviation from set point. It also responds quickly to the disturbances with some minimal overshoot. However, the disadvantage of poor performance has been observed in these controllers when manual tuning is used which in itself a monotonous process is. The PID controller using Ziegler-Nichols has more transient responses of satellite such as Overshoot, Settling time, and Steady state errors. For overcome this technique, the proposed analysis implemented an Adaptive Neural Network with PID tuning. The paper aims to combine two feedback methods by using neural networks. These methods are feed- forward and error feedback adaptive control. The research work is expected to reveal the inside working of these neural network controllers for state and error feedback input states. An error driven adaptive control systems is produced, when the neural networks acquire the knowledge of slopes and gains regarding the error feedback, while, with state feedback the system will keep trying to approximate a stable approach in order to stabilize the attitude of the satellite.*

Key Words: *Adaptive Neural Network, Control Algorithm, PID tuning, Rise Time, Overshoot, Ziegler-Nichols*

1. INTRODUCTION

A satellite requires high maneuverability, high pointing stability and attitude accuracy; these requirements are achieved by controlling the attitude of the satellite system. The attitude control is a crucial aspect in satellite design. The subsystems include sensors, actuators, control algorithm and other processes for the automatic control of the satellite [1], [2]. The proportional, integration and derivative (PID) scheme is used to optimize the satellite space dynamics systems so that by use of Adaptive Neural Networks (NN) the attitude of the satellite can be predicted with all the perturbations and errors taken into consideration. In this paper,

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Neural Networks will be considered using known examples of satellite attitude stabilization problems and hence use that knowledge to solve an unknown/new problem related to satellite stabilization.

2. LITERATURE REVIEW

Research papers related to basic space dynamics, optimization of PID controller for linearized Simulink model and neural networks were reviewed for the project. In the research paper, the authors, Ali Siahpush and Janet Gleave have discussed maintaining the basic structure of the satellite and determining the factors affecting the attitude control systems [2]. They also consider determining the vehicle and design requirements. This research paper had better performance characteristics than the traditional concepts. The results were efficient in complex situations like the satellite orientation problems. The study has the advantage of discussing the momentum devices and cost reductions measures that can be undertaken.

The research paper by Mohamma-d Shahrokhi and Alireza Zomorrodi on the comparison of PID controller tuning methods [3]. The authors discuss with the tuning of different orders and distinguished of load disturbances and set point changes. Open loop and closed loop systems have been considered.

While, another research paper on artificial intelligence use in spacecraft, written by Dario Izzo, Marcus Martens and Binfeng Pan, describes a Comparative Study of under strong scientific influence for successful missions [4]. He discuss the highlighted game changing and innovative techniques and deep Learning and Neural Networks is highlighted as key factors of making these techniques for robust.

The work Attitude Control of Small Satellite using Fuzzy Logic by the Bertrand Petermann is very useful to understand the fuzzy logic controller effectiveness [5].

A comparison of the attitude estimation Techniques for low-cost unmanned aerial vehicles by Harris Teague offers an overview of a relatively simple complementary filter combining accelerometers, gyroscopes and magnetometer sensing properties and focus was on highly dynamic manoeuvres [6].

Ismailova, Karlyga Zhilisbayeva discuss the Earth’s Magnetic field kept as reference to distinguish the trajectories and establish a proper stabilisation system [7]. The Derivation of Equations for Electric and Magnetic Fields of Earth and their influence is studied. An idea of varying magnetic field lines simulation has been established from this review.

A Neural Network Satellite Attitude Controller with Error Based Reference Trajectory by Valdemir Carrara and Atair Rios Neto has been reviwed to understand feed forward neural networks. Back propagations Algorithm with parallel processing structure to handle large amounts of data is established. Elaborative Training Techniques have been used in this paper [1]. The result was a comparison between ANN (Non-Linear) methods and PD controllers. From this paper it turned out that a very large training time is required for adaptive neural networks.

3. METHODOLOGY

The first step in the methodology process is to take input data from the sensors in the satellite or from the Simulink model of the satellite. Then these data are converted to quaternion for more precession attitude of the satellite. Then, the satellite attitude is measured using attitude quaternion. The process 3 lists the possible results from the above process and simultaneously stores them in the database.

The process is the filtering of the data from noise and perturbations by use of Kalman filters, extended Kalman filters etc. Process 5 is the optimization of the system using genetic algorithm by using a pre tuned PID controller. Process 7 consists in comparing the basic radial function and the spatial-temporal NN, and then the training model was created. Then the global error analysis process will take place.

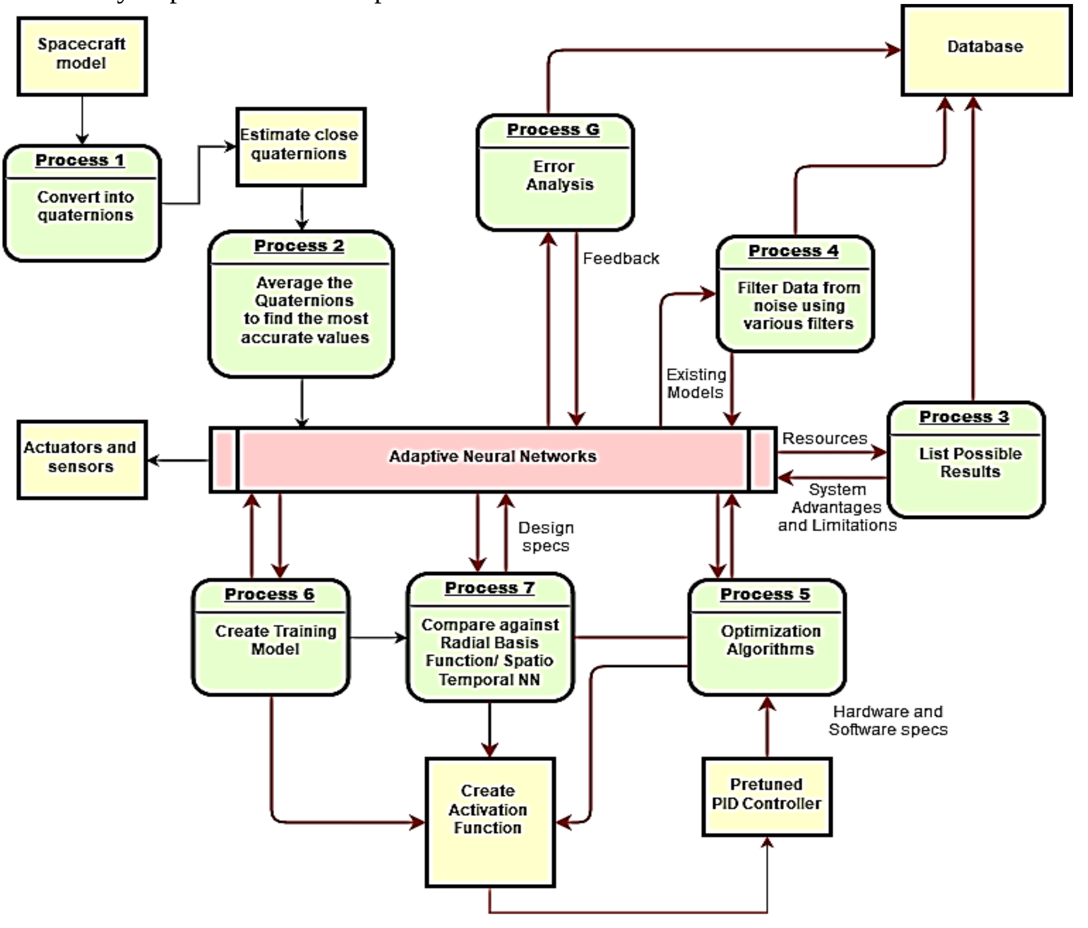


Fig. 1 Flowchart explaining the methodology

Averaging of quaternion

In order to achieve an optimal accuracy we often use multiple quaternion data while estimating the attitude. Therefore, in order to focus on this four dimensional Gaussian distribution we need to minimize the cost function of the quaternion. A scalar weighted case is not able to provide results without having some discontinuities. The quaternion is considered as Eigen Value or vectors. This minimizes the weighted sum of lengths of vector paths and the error quaternion algorithm for neural network training model [8].

Setting the weights

There are two basic methods of setting the weights to enable the process of learning or training known as supervised training and unsupervised training. The first method involves a teacher who knows the target output.

Therefore, this method compares the output with the expected response. In contrast, the second method is assumes the result is not known [9], [10].

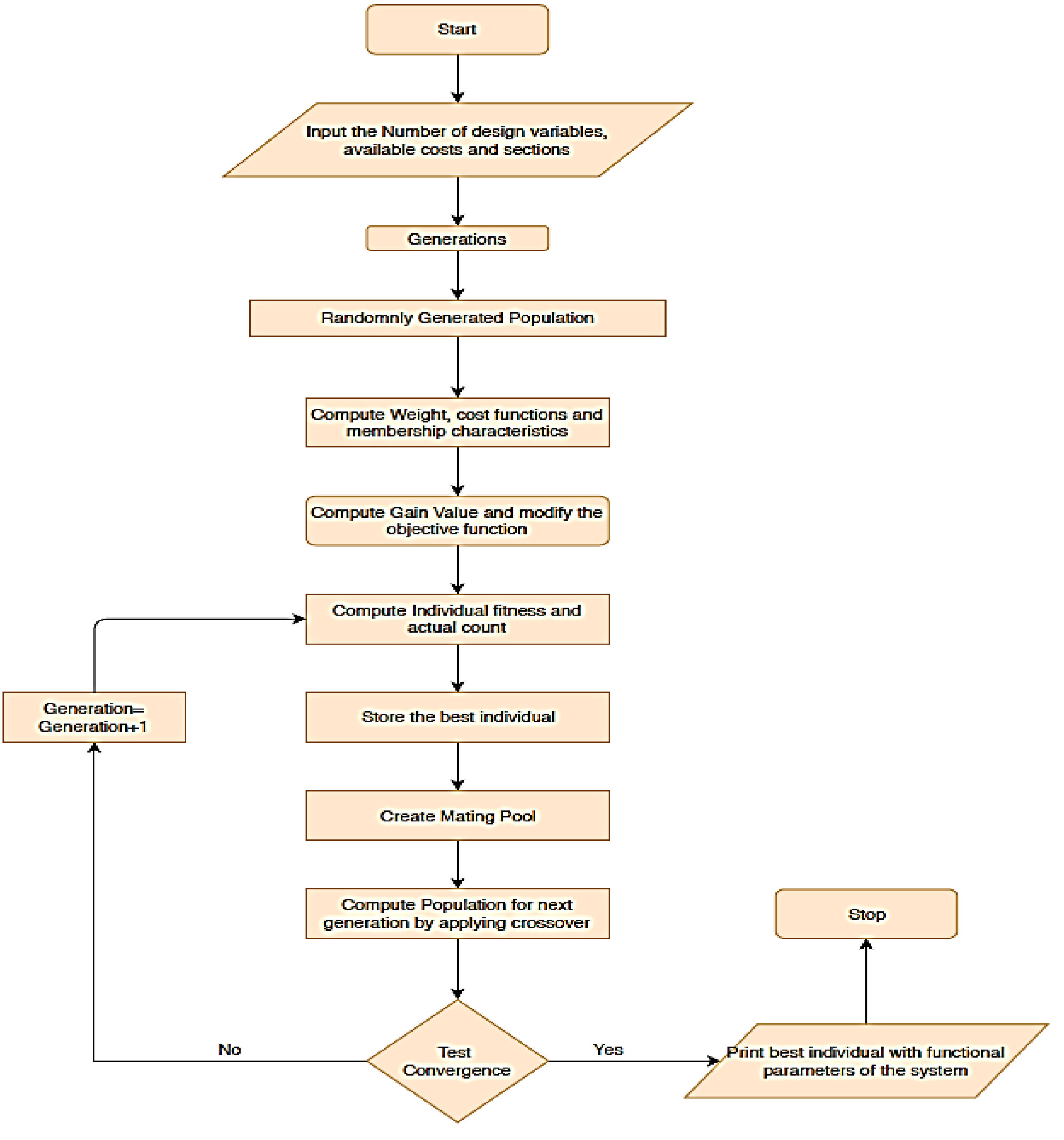


Fig. 2 NN training model

Supervised Training

A series of sample inputs are fed into the system, which are compared with the corresponding outputs for the expected results. This process continues until the expected results are achieved.

Unsupervised Training

This type of training is implemented by the first formation of the input vector, while the target result is not yet known.

The net may modify the weights so that the most similar input vector is assigned to the same output unit.

Iterations through the process and looping connections back into feedback layers are made until some sort of stable recall can be achieved [11], [12].

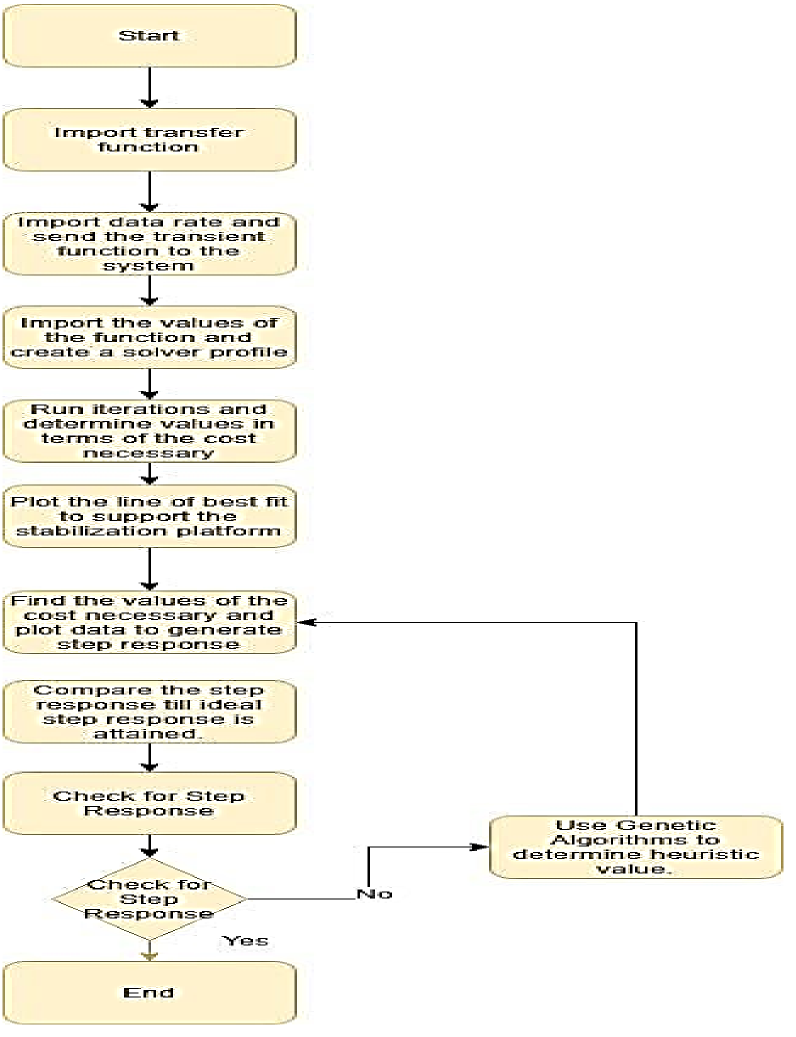


Fig. 3 Genetic Algorithms (PID Optimization)

Reinforcement Training

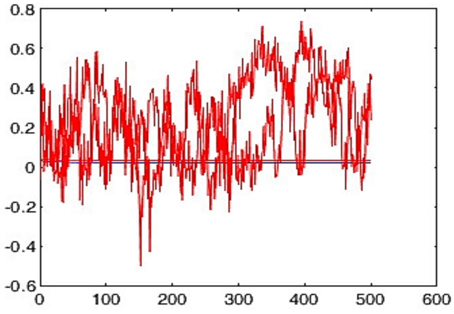
In this type of training the input vectors are trained and the output vectors are checked whether they are right or wrong. The performance is improved when this information is used by the network [13].

4. RESULTS AND DISCUSSIONS

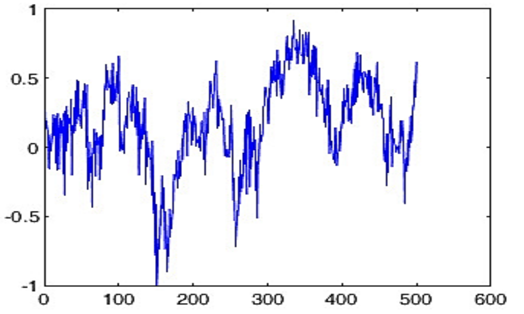
A. Robustness of feed forward and back propagation Neural Networks

PP=0.0341 for iterations 500, where PP is the cost. Error divergence is 0.0221 for iterations 500.
PP= 0.022, for iterations 8000.
Error divergence is 0.0130, for iterations 8000.
Our efficiency was increased by 41% and our system was able to use less computational power with time. If we give the system a parallel computing mode then the time that was taken by

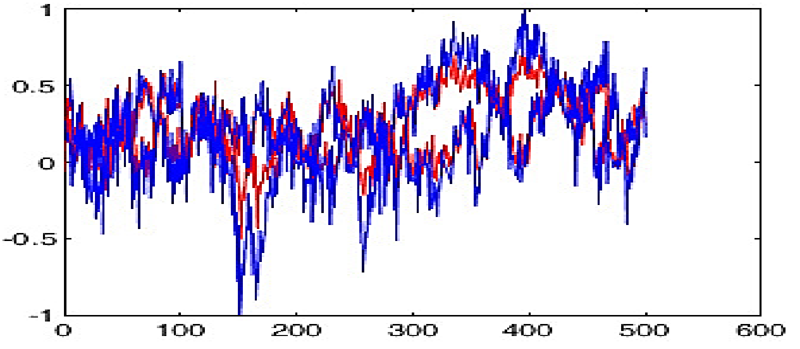
the NN would be reduced from 11 minutes to 3 and a half minutes while it was working on real time data.



(a)



(b)



(c)

Fig. 4 (a) & (b) Equal Training model (c) Unequal training model
Amplitude vs. Time

Figure 4(c) represents two different signals of unequal amplitudes and checks if after the iteration the generated values have the optimum result expected from the neural network. This method utilizes the backpropagation method which runs the data over and over again until an interpolated signal is given which provides us with efficiency in predicting the values further.

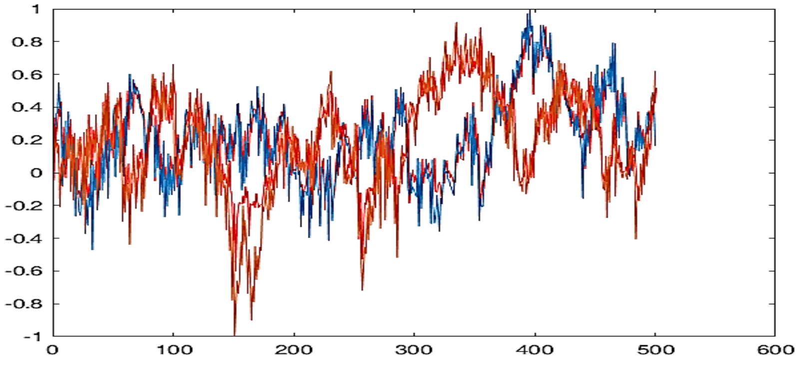


Fig. 5 Graph for the overall function

Figure (5) represents the overall function with interpolated.

B. Simulink model of satellite simulator

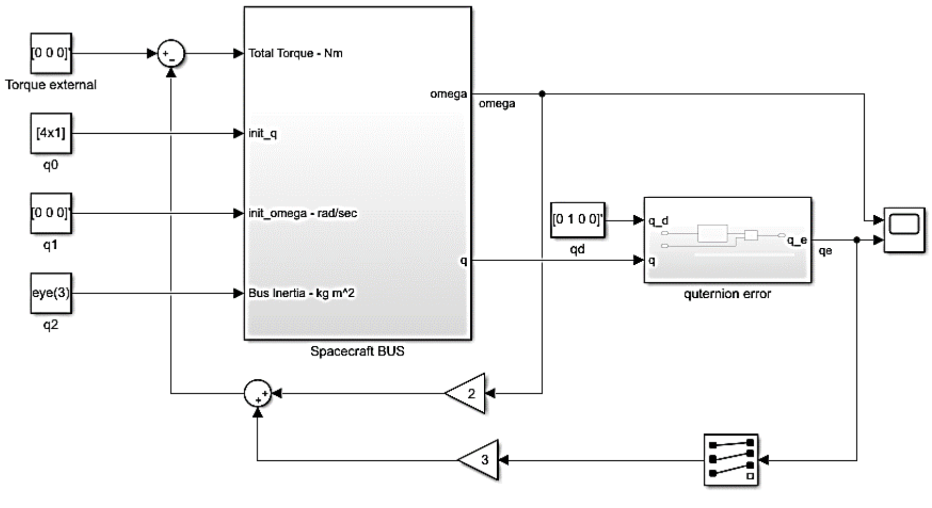


Fig. 6 Simulator Simulink model

The Satellite is initialized here with the external torque values and quaternion data and it fetches out the variation of the rotation angles and quaternion data in each of the axis [14].

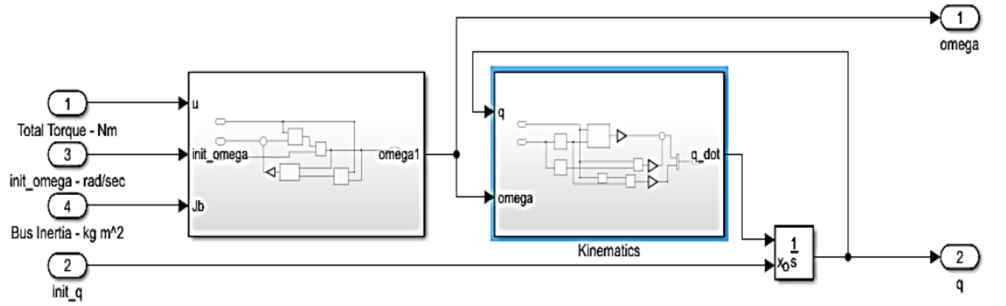


Fig. 7 Subsystem

The subsystems shown in Figure (7), to calculate errors generated and the solved data achieved after processing.

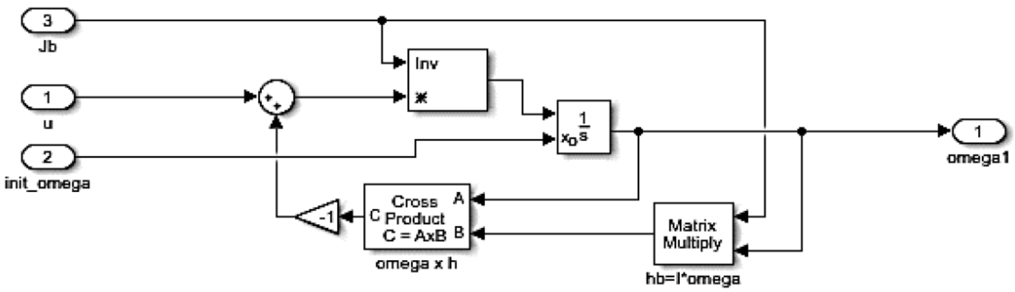


Fig. 8 Subsystem

To obtains the rotational matrix in order to get the right value of omega so that it can be routed further in the system [15].

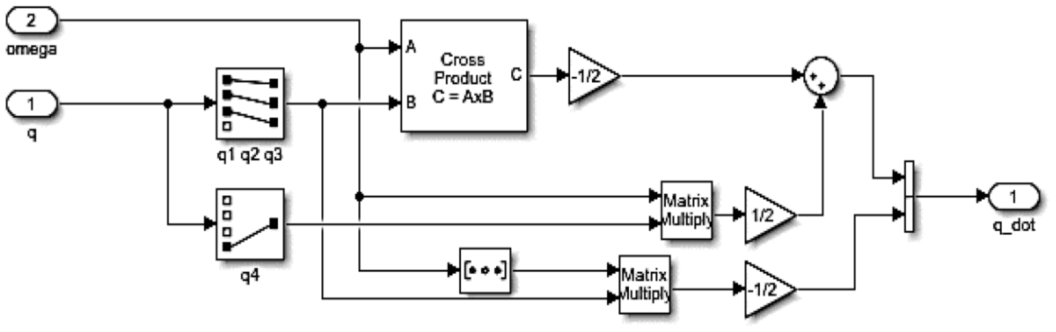


Fig. 9 Post DCM matrix conversion

This represents the post DCM matrix conversion to obtain the matrix multiplication in order to analyze the appropriate error in the system as well as future proof of the system for faulty noise that might be introduced into the system.

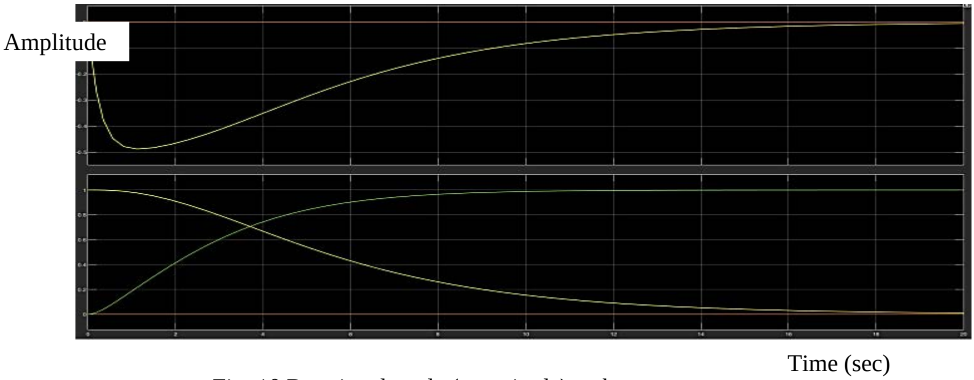


Fig. 10 Rotational angle (magnitude) – above response
Quaternion (magnitude) – Below Response

Fig. 10 Represents the rotation angle obtained from the spacecraft Simulink model and the quaternion approximation obtained for the satellite. The data is transferred to Adaptive Neural Network model representation with data accuracy. [16].

C. PID Controller Tuning and optimization using genetic algorithm

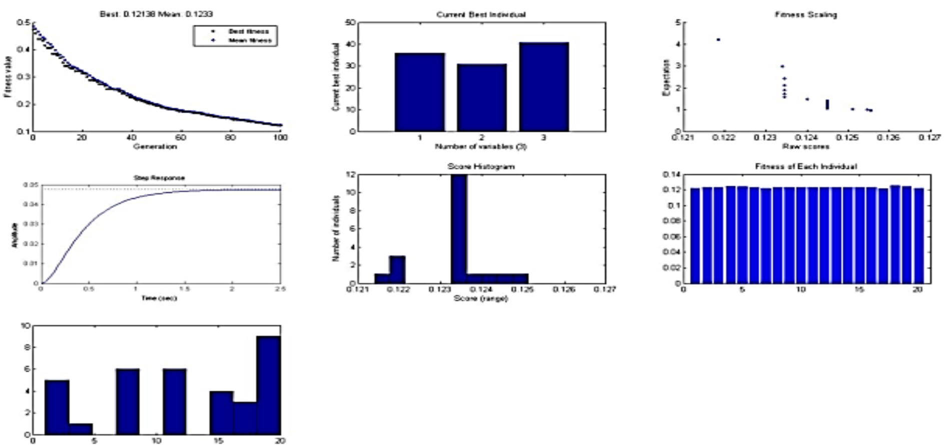


Fig. 11 Genetic Algorithm driven transfer function data attained for 100 iterations

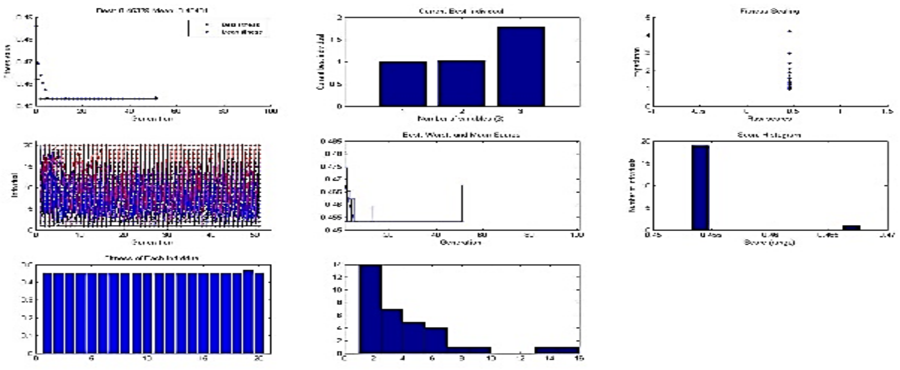


Fig. 12 Genetic Algorithm driven transfer function data attained for 500 iterations

Fig. 11 & 12. To illustrate the genetic algorithms to achieve an information such as, best fitness vale with generation progresses, best-optimized variables with proportional-integral-derivatives (PID) control of specified iteration criteria, for further analysis the fitness scaling were used. The step responses of system to predict the variables and optimized results of attitude data.

However, the computing load to keep a counter for measure best mean of the system. The best mean score shown in Fig. 11.

5. CONCLUSIONS

In this paper, an Adaptive Neural Network is developed and implemented by quaternion and Euler angles. A genetic algorithm has been implemented for the optimization of PID satellite attitude dynamics and control system. The system will predict the satellite attitude responses and optimize the performance to make the further controls for attitude with perturbation of the satellite.

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