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Positioning Control of Satellite Antenna for High Speed Response Performance

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Abstract

Dish antennas are essential elements in establishing communication between satellite and earth station. The response speed of the position control process of a dish antenna mounted on a moving vehicle that communicates via NigComSat-1R with a central control office is affected by round trip or time delay. Therefore, there is need to design a control system that will address this problem in order to achieve high speed positioning response. The mathematical models representing the dynamics of the antenna positioning system were obtained. A back propagation neural network (BPNN) based proportional integral and derivative (PID) controller was designed and added to the antenna position control loop. The resulting system was modelled in MATLAB. Simulation results indicated that it provided a rise time of 0.027 s, settling time of 1.06 s and overshoot of 0% at peak time of 0.06 s. This shows that the response speed of the control process using the designed BPNN-PID is 37 degree per second. Comparison with previous controllers applied to the same system indicated that BPNN-PID controller outperformed all of them. Generally, the BPNN-PID controller is suitable for high speed position control of the antenna and improves overall performance.

Keywords: Back propagation neural network; Controller, PID; Position control; Satellite antenna

1. Introduction

Proportional integral and derivative (PID) controllers have been widely applied in positioning control of satellite antenna. For instance, PID controllers and other classical control systems have been used to improve the positioning response of a satellite antenna mounted on distributed mobile telemedicine node [1-4] cruising within Nigeria and communicating via national satellite system called NigComsat-1R, which has shown to suffer from performance degradation due to associated time delay during communication [5]. This results in internal delay to control process, which complicates the system dynamic behaviour and largely hinders effective communication. However, classical control techniques such as PID controllers need to be designed based on the plant or process model and as a result, any mismatch in the plant model such as change in parameter, will result in poor control performance of the system. Hence, this paper aims to design a control system that can ensure that the satellite antenna system follows desired performance criteria even in the presence of changes in system dynamics characteristics or parameter variation using a back propagation neural network (BPNN), which is machine learning algorithm, to optimize the parameters of PID controller.

Other control strategies to replace or enhance classical controllers have been recently applied in antenna position control system in other applications. PID based control systems have widely been implemented using different tuning techniques. For instance, the position of a deep space antenna was controlled using weighted Cultural Artificial Fish Swarm Algorithm (wCAFSA) based PID controller [6]. The transient response of antenna azimuth position control system was improved using Genetic Algorithm (GA) based fractional order PID controller [7]. The problem of pointing accuracy was solved for a deep space antenna using fuzzy-PID [8]. Particle Swarm Optimization (PSO) was used to tune the parameters of PID and nonlinear PID (NPID) controllers to improve the transient and steady state performance of antenna azimuth positioning system [9]. In [10], a compensator optimized by PID algorithm using the control and estimation tool of MATLAB was used to achieve position control of direct current (DC) servomotor-based antenna. Classical PID controller-based Ziegler-Nichols method was shown to provide efficient performance for antenna position system that uses DC servomotor [11]. PID, Linear Quadratic Regulator (LQR), and Fuzzy-Proportional and Integral (Fuzzy-PI) models were used as control systems to achieve positioning of satellite antenna for Ground Data Receiving Stations (GDRS) [12]. Fuzzy logic controller (FLC) and fuzzy-PID controller were separately used to enhance the loop of position control system for satellite tracking antenna though the fuzzy-PID provider better performance [13]. In order to address the problem of state steady error associated with FLC, [14] introduced three FLC based control system called fuzzy proportional and derivative logic controller (FPD), FPD with integral controller (FPDI), and FPD plus integral controller (FPD+I). The results presented revealed that the FPD+I outperformed the other controllers in terms of reduced steady-state error with the best tracking performance. Classical PID controllers offer simplicity in control system design and high reliability (in terms of steady state error), and provide shorter time to reach steady state (or stability) compared with fuzzy PID control [15]. Transient efficiency can be increased by using PID to improve steady-state error [13]. However, classical PID control system is usually prone to overshoot and parameter variation such that in most cases, intelligent algorithms such as GA, PSO, and fuzzy logic, are often used to tune the PID to overcome these limitations as in [15,16]. FLC is regarded as one of the most common control schemes for addressing nonlinearity and uncertainty in systems [13,14]. Despite the fact that these intelligent schemes are used to address the limitations of PID controllers, strengthen their performance with adaptive capability and more appropriate for nonlinear control system [15], some weakness still exist. For instance, the drawbacks of FLC system are as result of the complexity in determining accurate membership functions and absence of logical method for transforming expert knowledge into rule base and a lot of time is consumed in tuning parameters [17]. Fuzzy logic controller suffers from steady state error [14,18,19]. Sub-par timing precision and limited anti-interference capabilities are challenges of expert PID and fuzzy-PID controllers [20] including an extensive amount of computation and some lag [15]. Even though GA has proven to be promising in optimizing PID parameters, its two main disadvantages are poor early convergence and loss of best fitness found [21,22]. Also, finding a global optimum by GA is not absolutely guaranteed [22].

State feedback control technique has been shown to outperform Ziegler-Nichols tuned PID controller in position control of antenna's azimuth [23]. Linear Quadratic Gaussian (LQG) controller was applied in ship-borne UXB antenna servo system to reduce pointing and tracking error so as to ensure directional and tracking accuracy [24]. LQR was used to provide optimal control for DC servomotor-based antenna positioning system and was shown to yield better results than PID controller [25]. When optimal control is desired with improved rise time, fast settling time, overshoot, and zero tracking error, LQG, LQR, and state feedback schemes are good candidates. However, just like PID controller, the optimal gain matrices of LQG and LQR are fixed and could be affected by mismatch in system parameters [26] such that frequent updated or redesign by adjusting the gains to adapt to changes in system behaviour may be required.

Stability in antenna azimuth was achieved using Model Reference Adaptive Control (MRAC) based on the method of gradient approach and Lyapunov technique [27]. The implementation of MRAC and Self-tuning Controller (STC) for antenna position control system revealed that the offer adaptation capability to changing in conditions of the environment, though STC yielded better performance than MRAC with respect to fast response and less oscillation [28]. Servo position control system was designed using Model Following Control based PID (MFC-PID) controller in [29]. MRAC utilizes the difference between actual output and reference model to provide adaptive features for control system [26]. However, the knowledge of the plant model, which may be the mathematical description of the plant dynamics including limit of operation, is still required to an extent for adaptive controllers [30] such as MRAC. The robustness of the stability of adaptive control system is difficult to measure [31].

The problem of internal and external disturbances has been addressed in antenna positioning control in order to achieved stability using Model Predictive Control (MPC) [32]. For MPC, the controller can implement constraints within it and thereby eliminating the prospect of variables exceeding their limits, which is a highly desired feature [33]. Uncertainty in plant knowledge (or nonlinearity in plant model) is still a major challenge in MPC despite being considered a major control choice to address several difficult control problems [34]. MPC was shown to yield higher gain in high frequency range and as such become sensitive to measurement noise [35]. Large number of model coefficients is often required to describe a response in MPC and incorrect formulation of prediction horizon can render control performance poor even if the model is accurate [33].

The proposed BPNN-PID control model offers rapid adjustment velocity and exceptional accuracy, while eliminating the effect of internal delay associated with the control process for improved tracking performance and pointing accuracy. The BPNN-PID controller can work well in the presence of nonlinearities since it is good candidate for controlling time-varying and time delay system. With the proposed control technique for satellite tracking system, the observed limitations from the literature review are addressed by the controller leveraging advantages of BPNN while ensuring that the control process does not require the intervention of operators with specific expertise or knowledge.

Generally, the objectives of the paper are to design PID controller whose parameters have been optimized or tuned by intelligent algorithm and to eliminate round-trip time delay that impacts on a satellite antenna position control system using the designed intelligent based PID model. Thus, the contributions of this paper are the use of intelligent based PID model to enhance positioning control of satellite antenna for high speed performance and the development of an intelligent control algorithm that suppresses internal delay effect in satellite position control system.

2. Method

2.1. Mathematical Model of Satellite Antenna

The dynamic behaviour of the antenna positioning system is mathematically represented as a transfer function in terms of dish structure, actuator motor and jack. The dish structure moment of inertia, spring constant and damping coefficient, which are the dynamic characteristics of the antenna have been experimentally determined including the actuator and jack dynamics [2]. Therefore, the mathematical models of the antenna structure, motor and the jack gear ratio are defined in Equations (1) to (3) [2]:

$$G_p(s) = \frac{2.2578}{s^2 + 0.9016\ s + 2.2578} \tag{1}$$

$$G_m(s) = \frac{0.075}{s(1+0.015s)} \tag{2}$$

$$K_g = 0.033 \tag{3}$$

The time delay associated with the communication link for forward and feedback paths are defined by the transfer functions given by [2]:

$$\left.\begin{aligned} G_{d1}(s) &= e^{-T_1 s} \\ G_{d2}(s) &= e^{-T_2 s} \end{aligned}\right\} \tag{4}$$

where T_1 and T_2 are the forward path and feedback delay time in seconds respectively. Taking $T_1 = T_2 = T$, Equation (4) can be simply represented by [2,4]:

$$G_{d1}(s) = G_{d2}(s) = G_d(s) = e^{-Ts} \tag{5}$$

The time delays were found to be 0.2469 s and 0.2502 s for minimum and maximum values [2]. Nevertheless, T = 0.25 s is used in this paper. The closed loop block diagram of the system considering Equations (1) to (4) including a controller block is shown in Figure 1.

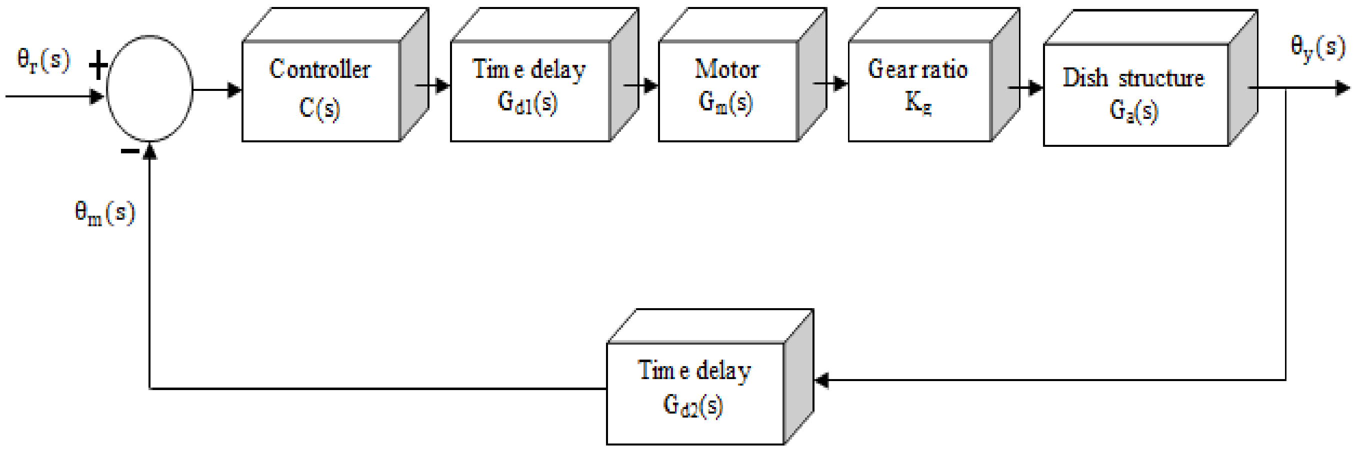

Figure 1. Block Diagram of Closed Loop Control System

The closed loop structure shown in Figure 1 represents the signal flow path of the control process for a single-input single-output (SISO) linear time-invariant (LTI) system that is impact by internal delay effect. For communication with satellite, the controller (situated at control office) utilizing the error signal due to the deviation of the actual (or current) position of the dish ($\theta_y(s)$) from the setpoint (reference) position ($\theta_r(s)$), wirelessly sends control signal via the motor and the gear ratio mechanisms that provide the necessary actuating force that moves or adjusts the dish structure according to command action of the controller. Forward path and feedback delays are experienced because of the wireless link of communication established via NigComsat-1R between the controller and the plant (situated at door) [2,5]. This process is repeated until the actual position of the dish structure aligns with the setpoint position which results in zero error that brings about the termination of the controller's action. At this point, the position control process for the satellite antenna stops. The forward path transfer function without the controller and the forward path time delay and the closed loop transfer function of the system excluding the controller considering Figure 1 are given in Equations (6) and (7) by:

$$G_p(s) = \frac{3.76e^{-Ts}}{s^5 + 67.56s^4 + 62.36s^3 + 150.52s^2} \quad (6)$$

$$\frac{\theta_y(s)}{\theta_r(s)} = \frac{3.76e^{-Ts}}{s^5 + 67.56s^4 + 62.36s^3 + 150.52s^2 + 3.7e^{-2Ts}} \quad (7)$$

Where $\theta_r(s)$ is the setpoint position of the antenna in degree, $\theta_m(s)$ is the measured position (Figure 1) and $\theta_y(s)$ is the actual position of the antenna in degree.

2.2. Modelling of BPNN Based PID Control System

The main tool used in this study is the MATLAB. The m-file as a vital programming language tool of MATLAB was used as a text file to develop and place MATLAB codes. A composite method has been adopted in this paper for the controller. The control objective is to improve the positioning speed of a satellite antenna (i.e. the plant) in telemedicine evaluated in terms of time domain performance characteristics of the system which includes rise time, settling time, and maximum overshoot. The requirements of these performance parameters are defined as rise time of ≤ 4 s settling time of ≤ 5 s and percentage overshoot of ≤ 10% and these values chosen conform to the standards of a practical industrial system [36].

Figure 2 is the structure of the proposed antenna positioning control system neural network PID control technique with back propagation based weight updating algorithm.

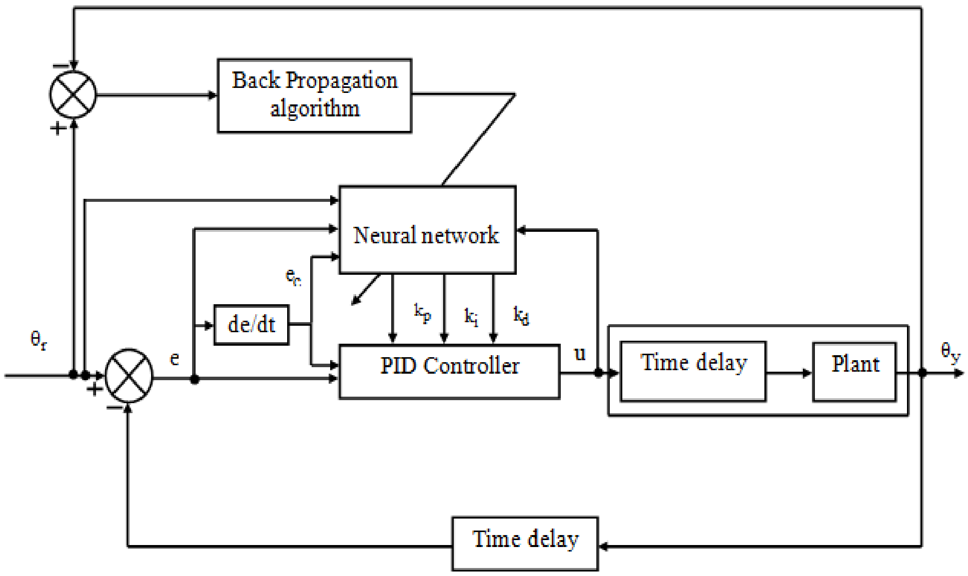

Figure 2. Proposed Control System for Positioning of Satellite Antenna

As shown in Figure 2, two parts are associated with the control technique: classical PID and the learning algorithm of BPNN. The system performance depends on the adjustment of the proportional gain, k_p integral gain, k_i

and derivative gain, k_d of the PID controller, which are automatically tuned by the learning algorithm. A gradient descent method based on-line training algorithm is used by the BPNN to update the network weights and ensure that the desired gains of the PID controller are ably computed by the neural network. Hence, the target position (reference input) is tracked and the expected output achieved while maintaining system stability.

- PID Controller

The implemented PID controller using BPNN algorithm is a discrete time control system. The control action of PID controller is given by:

$$u(t) = k_p\left(e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d\frac{d}{dt}e(t)\right) \tag{8}$$

Where e(t), k_p, T_i, and T_d are the error signal, the proportional gain, integral time constant and derivative time constant respectively. Equation (8) can be represented in discrete time form given by:

$$u(kT_s) = u(kT_s - 1) + k_p\left[e(kT_s) - e(kT_s - 1)\right] + \frac{k_pT_s}{T_i}e(kT_s) + \frac{k_pT_d}{T_s}\left[e(kT_s) - 2e(kT_s - 1) + e(kT_s - 2)\right] \tag{9}$$

where T_s is the sampling time, kT_s is the discrete sampling instants and can be simply expressed as $kT_s = k$ The integral gain, k_i and derivative gain, k_d can be defined as $k_i = k_pT_s/T_i$ and $k_d = k_pT_d/T_s$ Hence, the simplified incremental discrete time PID control action is given by:

$$u(k) = u(k-1) + k_p\left[e(k) - e(k-1)\right] + k_ie(k) + k_d\left[e(k) - 2e(k-1) + e(k-2)\right] \tag{10}$$

where e(k) is the system error in discrete time, and u(k) is the output of the PID controller in discrete time. Note, the value of the sampling time is 0.002 s.

- BPNN Based PID Controller

The structure of a four-input three-hidden and three-output layers BPNN used for optimizing PID parameters are shown in Figure 3. The BPNN has one hidden layer since this can be used by neural network to approximate any continuous function provided that there are sufficient amount of neurons.

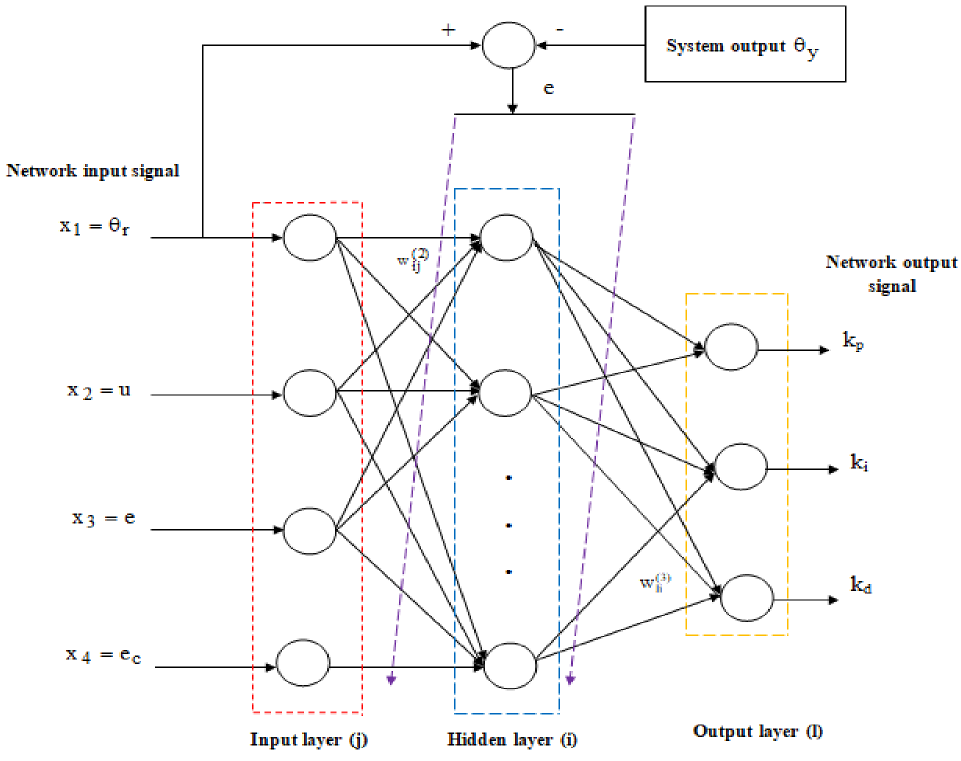

Figure 3. Structure of the BPNN Based PID Algorithm

Feed forward control: it should be noted that the superscripts (1), (2), and (3) are used to identify variables of input layer neurons, hidden layer neurons, and output layer neurons respectively. The four inputs of the neural network considering Figures 2 and 3 are given by:

$$x_j = (x_1 \quad x_2 \quad x_3 \quad x_4)^T = (\theta_r \quad u \quad e \quad e_c)^T \tag{11}$$

Where θ_r, u, e and e_c are the reference position or setpoint, the control command, the error signal and the change in system error respectively. The change in system error can be expressed as follows:

$$e_c(k) = e(k) - e(k-1) \tag{12}$$

Input layer-hidden layer connection: the output of each neuron in the input layer, input of each neuron in the hidden layer, the output of each neuron in the hidden layer and the activation function in the hidden layer that describes the input-output relation are given by (13) to (16):

$$O_j^{(1)} = x_j \qquad \{j = 1, 2, 3, 4\} \tag{13}$$

$$y_{in}^{(2)}(k) = \sum_{j=1}^{4} w_{ij}^{(2)} O_j^{(1)} \qquad \{i = 1, 2, \cdots, N\} \tag{14}$$

$$O_i^{(2)}(k) = f_1(y_{in}^{(2)}(k)) \tag{15}$$

$$f_1(x) = \tanh(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}}, \quad \{x = y_{in}^{(2)}(k)\} \tag{16}$$

Where $w_{ij}^{(2)}$ is the weight connecting the input layer neurons to the hidden layer neurons, N is the number of neurons in the hidden layer, f_1 is the activation function in the hidden layer that describes the relation between each neuron input and output.

Hidden layer-output layer connection: With output of the hidden layer determined as in (15), the input of each neuron in the output layer and the corresponding output are given by (17) and (18):

$$y_{in}^{(3)}(k) = \sum_{i=1}^{N} w_{li}^{(3)} O_i^{(2)} \qquad \{l = 1, 2, 3\} \tag{17}$$

$$O_i^{(3)}(k) = f_2(y_{in}^{(3)}(k)) \tag{18}$$

Since the outputs of the neurons in the output layer correspond to the PID parameters, (18) can be defined by:

$$O_1^{(3)}(k) = k_p \tag{19}$$

$$O_2^{(3)}(k) = k_i \tag{20}$$

$$O_3^{(3)}(k) = k_d \tag{21}$$

Where $w_{li}^{(3)}$ is the weight factor that connects the neurons of the hidden layer to the neurons of the output layer, and f_2 is the activation function in the output layer that defines the relationship between each neuron input and output. Thus, activation function for the input-output link in the output layer is given by:

$$f_2(x) = 0.5\,(1 + \tanh(x)) = \frac{e^x}{e^x + e^{-x}}, \quad \{x = y_{in}^{(3)}(k)\} \tag{22}$$

Weight update: the error function of the system output is defined by:

$$E(k) = 0.5\,(\theta_r(k) - \theta_y(k))^2 = 0.5(e(k))^2 \tag{23}$$

Prior to the use of neural network algorithm, training process must be performed. In the algorithm, repeated training process is carried out until the mean square error (MSE) of the training data attains the minimum desired value

[37]. The training process in this paper is based on back propagation. This involves the use of gradient descent technique on the error function to adjust the neuron weights in an iteration process. Each weight from hidden layer to output layer is generally adjusted using the expression defined by:

$$\Delta w_{li}^{(3)}(k) = -\mu \frac{\partial E(k)}{\partial w_{li}^{(3)}} \tag{24}$$

In order to prevent the problem of local minima, which is common to back propagation algorithm, a momentum term is added to the weight change [37]. Therefore, the adjustment of each weight from hidden layer to output layer is enhanced in terms of the output error of the system given by:

$$\Delta w_{li}^{(3)}(k) = -\mu \frac{\partial E}{\partial w_{li}^{(3)}} + \beta \Delta w_{li}^{(3)}(k-1) \tag{25}$$

Where μ and β are the learning rate and momentum factor respectively. The partial derivative of the error with respect to the weight from hidden layer to output layer can be defined by:

$$\frac{\partial E(k)}{\partial w_{li}^{(3)}(k)} = \frac{\partial E(k)}{\partial \theta_y(k)} \cdot \frac{\partial \theta_y(k)}{\partial u(k)} \cdot \frac{\partial u(k)}{\partial O_l^{(3)}(k)} \cdot \frac{\partial O_l^{(3)}(k)}{\partial y_{in}^{(3)}(k)} \cdot \frac{\partial y_{in}^{(3)}(k)}{\partial w_{li}^{(3)}(k)} \tag{26}$$

But the ratio of the input of the output layer to the weight factor is equal to the output of the hidden layer and this can be expressed in terms of partial derivative given by:

$$\frac{\partial y_{in}^{(3)}(k)}{\partial w_{li}^{(3)}(k)} = O_i^{(2)}(k) \tag{27}$$

Also, the incremental algorithm of the PID control system can be defined by taking the partial derivative expression for the command input with respect to the PID parameters as in (10). Thus:

$$\frac{\partial u(k)}{\partial O_1^{(3)}(k)} = e(k) - e(k-1), \quad \{\partial O_1^{(3)} = k_p\} \tag{28}$$

$$\frac{\partial u(k)}{\partial O_2^{(3)}(k)} = e(k), \quad \{\partial O_2^{(3)} = k_i\} \tag{29}$$

$$\frac{\partial u(k)}{\partial O_3^{(3)}(k)} = e(k) - 2e(k-1) + e(k-2), \quad \{\partial O_3^{(3)} = k_d\} \tag{30}$$

In the output layer, the weighted update learning algorithm is defined by:

$$w_{li}^{(3)}(k+1) = w_{li}^{3}(k) + \Delta w_{li}^{(3)}(k) \tag{31}$$

$$\Delta w_{li}^{(3)}(k) = \beta \Delta w_{li}^{(3)}(k-1) + \mu \sigma_l^{(3)} O_i^{(2)}(k) \tag{32}$$

Where $\sigma_1^{(3)}$ is the required hidden layer error function for weight adjustment between output layer and hidden layer for the back propagation and it is given by:

$$\sigma_l^{(3)} = e(k). \frac{\partial \theta_y(k)}{\partial u(k)} \cdot \frac{\partial u(k)}{\partial O_l^{(3)}(k)} \cdot f_2'(y_{in}^{(3)}(k)) \tag{33}$$

Where f_2' is the derivative of the function f_2 defined by:

$$f_2'(x) = f_2(x)\left(1 - f_2(x)\right) \tag{34}$$

The learning algorithm can be defined based on the gradient descent technique for input layer and hidden layer for the back propagation by:

$$w_{ij}^{(2)}(k+1) = w_{ij}^{(2)}(k) + \Delta w_{ij}^{(2)}(k) \tag{35}$$

$$\Delta w_{ij}^{(2)}(k) = \beta w_{ij}^{(2)}(k-1) + \mu \sigma_i^{(2)} O_j^{(2)}(k) \tag{36}$$

$$\sigma_i^{(2)} = f_1'\left(y_{in}^{(2)}(k)\right) \cdot \sum_{l=1}^{3} \sigma_l^{(3)} w_{li}^{(3)}(k) \quad (37)$$

Where f_1'stands for the first derivative of f_1 given by:

$$f_1'(x) = 0.5\left(1 - f_1^2(x)\right) \quad (38)$$

With the BPNN-PID model established, a flowchart for the overall control process for the proposed system is shown in Figure 4.

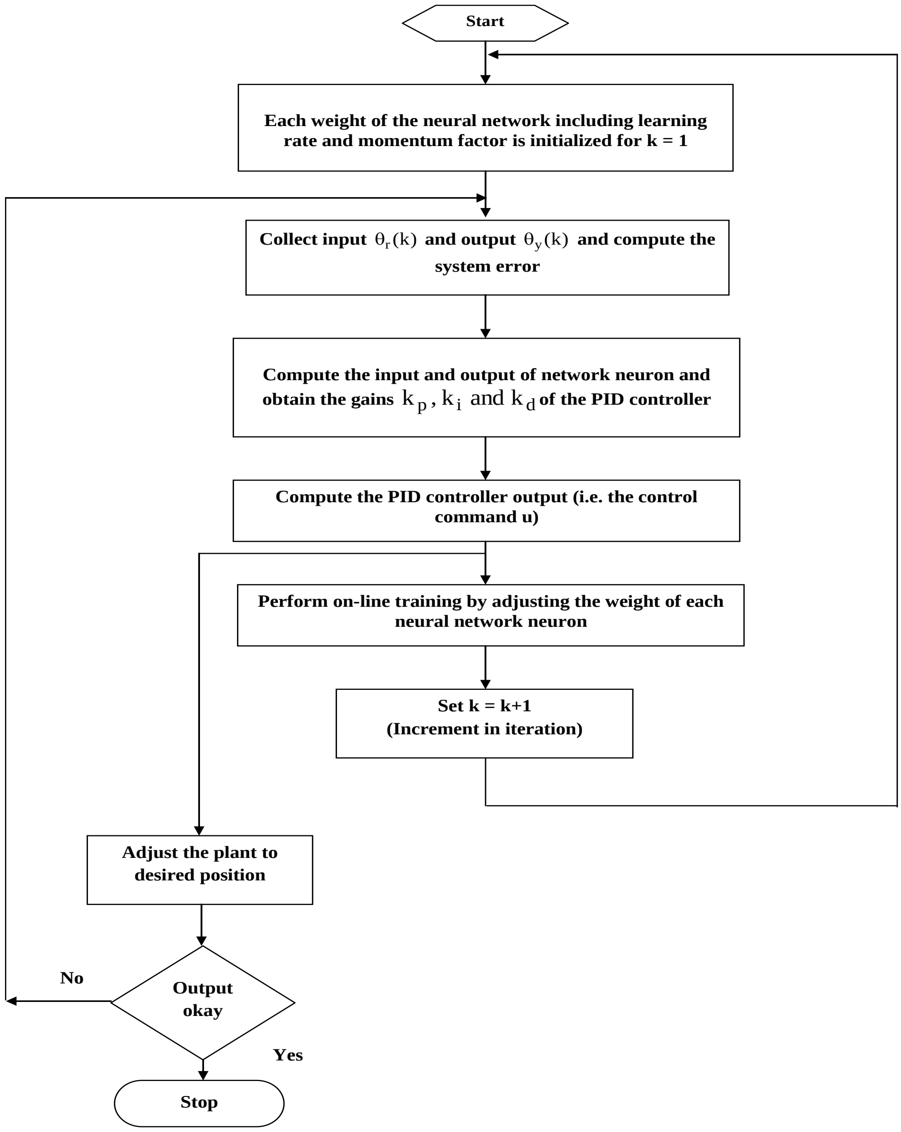

Figure 4. Closed Loop Control Flowchart of the BPNN-PID Technique

3. Results and Discussion

The results obtained from the simulation analyses carried out in MATLAB environment are presented in this section. The simulation analyses are presented in terms of three scenarios considering the application of unit step input in degree. The scenarios consist of step response performances of uncompensated system (system without controller), BPNN-PID control system (simulation of the proposed system), and the simulation of other control strategies that have been implemented in previous studies with respect to the position control of the considered antenna in telemedicine.

3.1. Simulation of System without Controller

Figure 5 shows the step response plot of the system when no controller was added to the closed loop positioning control system for dish antenna. The curves represents the actual position (or output) of the system when control is only achieved as a result of the movement of the antenna by the action of the actuator (motor).

As shown in Figure 5, looking at the horizontal axis of the step response plot, it can be seen that the step response of the uncompensated system has prolonged time profile that can be attributed to the effect of delay, which is not compensated for in the system. Thus, the resulting time domain parameters of the uncompensated system are stated in Table 1.

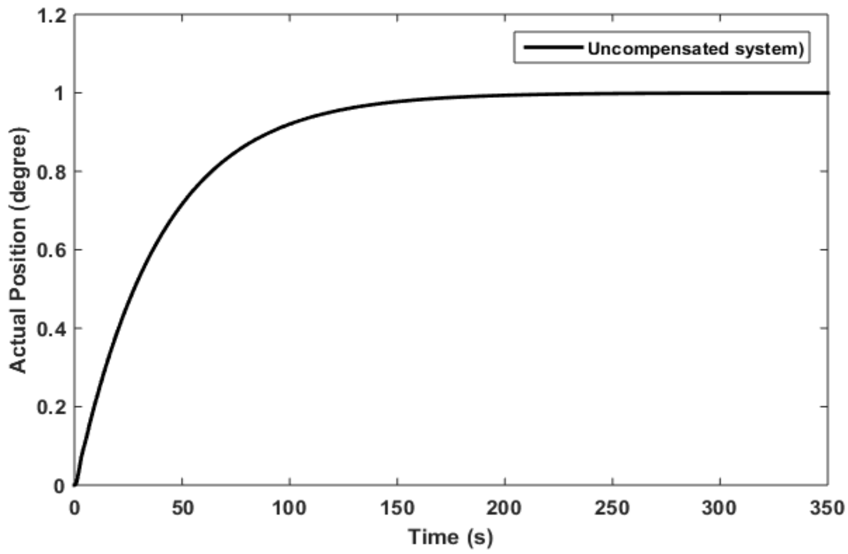

Figure 5. Uncompensated Dish Antenna Control System Response

Table 1. Numerical Presentation of Uncompensated System Response

Parameter	Value
Rise time (t_r)	86.6 s
Settling time (t_s)	154 s
Peak time (t_p)	350 s
Overshoot (M_p)	0
Steady state error (e_{ss})	0

Remarkably, the system time domain performance characteristics indicate a time consuming process if the system were to operate in this scenario, and this will adversely impact on the timing (or speed) required for efficient satellite communication. Therefore looking at Table 1, it can been seen that with rise (or response) time of 86.6 s to unit step input in degree, the rate (or speed), i.e. $1/t_r$ with which the control process will commence in order to position the antenna for satellite communication is 0.012 degree per second. Generally, the system rise time including the speed in the uncompensated condition is very low.

3.2. Simulation of System with BPNN-PID Controller

Having carried out many simulation tests, the finest initial values for the learning rate and momentum factor were set as 0.22 and 0.024, while the neural network weights were randomly initialized in the range of -0.5 to 0.5. Even though by randomly selecting the pre-set weights, little unsteadiness to control process may occur, the back propagation model can make swift response to any mismatch or variation in parameters and as such the neural network weights in relative short time are updated to make sure the desired output is achieved.

With unit step input introduced at time t = 0, the actual position of the proposed system is as shown in Figure 6. As can be seen from the simulation plot looking at the horizontal axis, the timing of the process required to effectively control the dish antenna to meet targeted position has been significantly reduced to a large extent. Thus, the performance characteristics of the system are defined in Table 2.

Figure 7 shows the output (or control action), u(k) of the PID controller tuned by the BPNN algorithm.

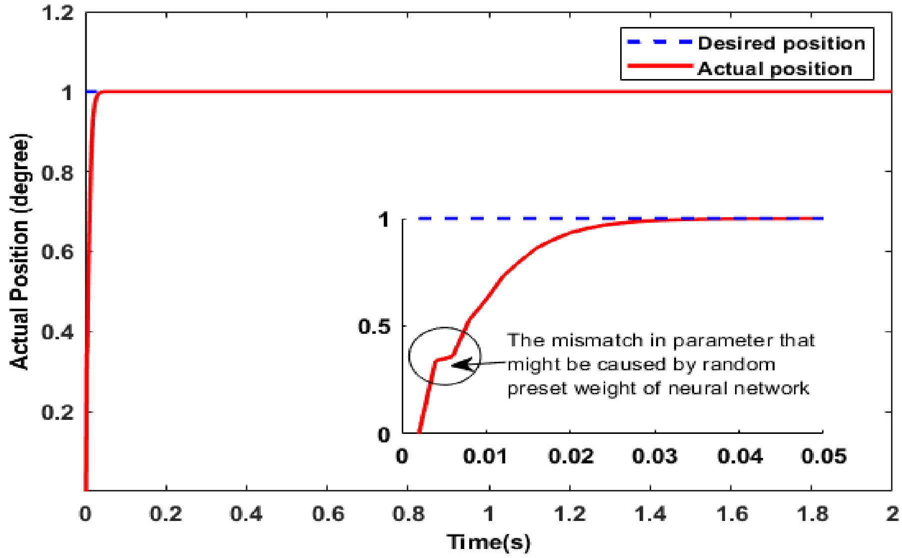

Figure. 6 Step Response of BPNN-PID Control System

Table 2. Numerical Presentation of BPNN-PID System Response

Parameter	Value
Rise time (t_r)	0.027 s
Settling time (t_s)	1.06 s
Peak time (t_p)	0.06 s
Overshoot (M_p)	0
Steady state error (e_{ss})	0

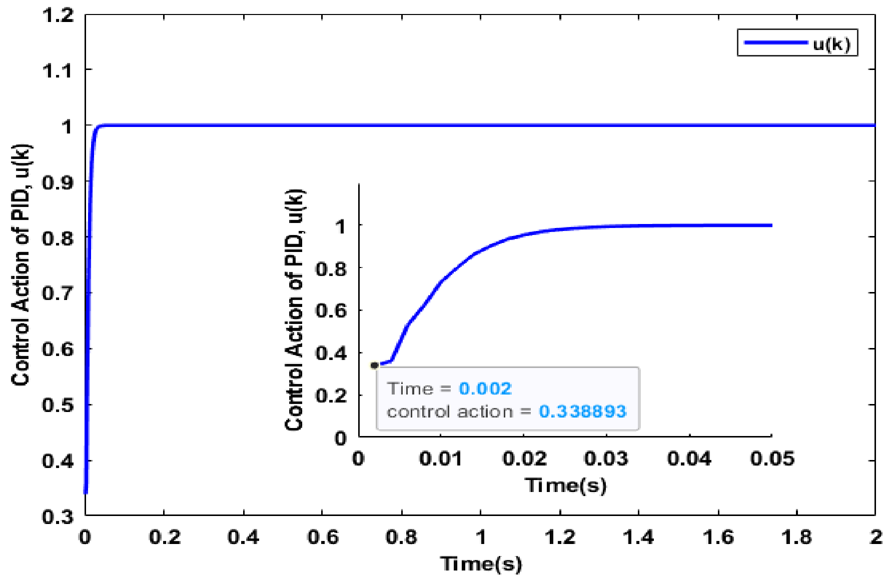

Figure 7. Response Plot of BPNN-PID Control Variable

The subplot inserted in Figure 7 shows the effect of mismatch that the random pre-set weight values of the neural network might have caused and this occurred at 0.004 s even before the rise time. However, this mismatch or variation in system parameter has no significant effect on the system. That is, it does not cause any significant disturbance to the control of the plant since this occurs at the beginning of the response even before the rise time. Hence the system is brought back to the setpoint path by the action of the back propagation algorithm as the response approaches the rise time. Generally, the system has very fast step response.

It can be seen that the step response curve of the control variable $u(k)$ (Figure 7) is very much similar to the actual output shown in Figure 6. The control variable is computed by the PID controller and then applied to the antenna, which changes its position according to the control command signal. The subplot in Figure 7 indicates that the effect of mismatch occurs at 0.002 s. Hence, it suffices to say that the obvious similarity of the control action of the BPNN based PID controller and the system output shown in Figure 6 proves the effectiveness of the proposed system. Also, the ability to ensure system adaptability to change in parameters during control process is provided by adjusting the system to the path of the setpoint value when mismatch occurs prior to rise time. Generally, this performance proves that the proposed system ensures fast, accurate and efficient control. Also, looking at Table 2, the rise time is 0.027 s, which means that the response speed of the control process using the designed BPNN-PID is 37 degree per second.

The error curve shown in Figure 8 reveals that at t = 0 when the unit step input was just applied, the deviation of the actual position (system output) from the setpoint (desired position) was high but reduces to zero as the system reaches the target position within the time bound of the control process.

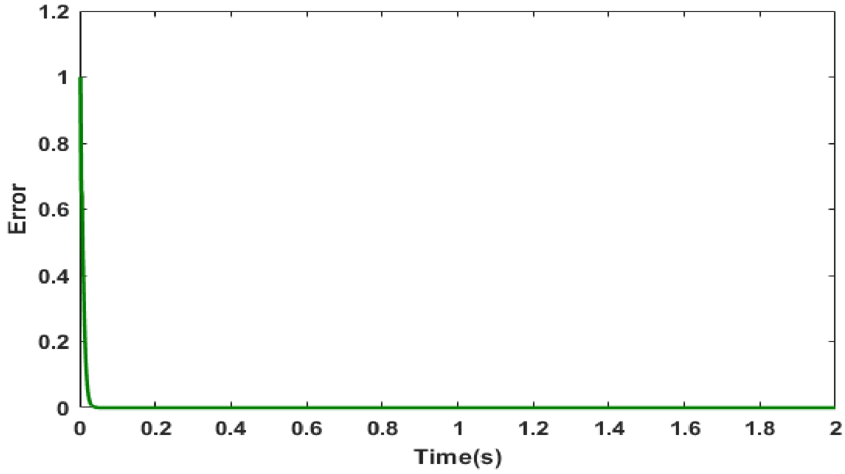

Figure 8. Error Plot of BPNN-PID Control Process

Figure 9 shows the auto-tuned parameters of the PID controller k_p, k_i, and k_d by the BPNN algorithm. The curves show that at the beginning of the control process, the parameters of the PID controller were: kp =0.1901, ki = 0.1297, and k_d = 0.01902 With the continuous auto-tuning of the PID parameters, the values keep modifying so as to optimize the transient performance of the control process until a steady state is reached by the system. Thus, as steady state is attained by the system, the parameters of the auto-tuned PID settle at optimized values of kp = 0.2850, ki = 0.4410 and kd = 0.0964 then remain stable. Looking at the curves of the auto-tuned PID parameters, it can be seen that the performance further validates the effectiveness of the proposed system.

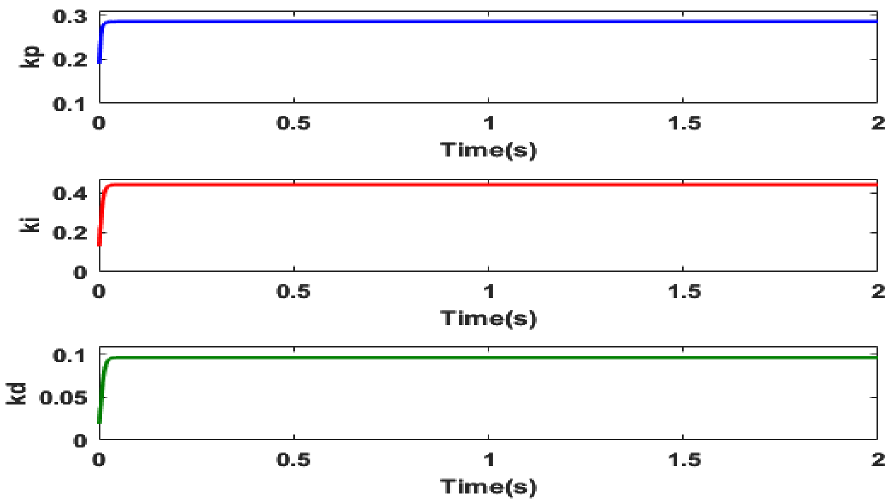

Figure 9. Plot of Auto Tuned PID Parameters

Figures 10 to 13 show the relationship between the parameters of the auto-tuned PID controller and the inputs of the neural network in the proposed control technique given by (11). That is to say, the auto-tuning of the neural network is a function of these variables, which are used to regulate the parameters of the PID controller.

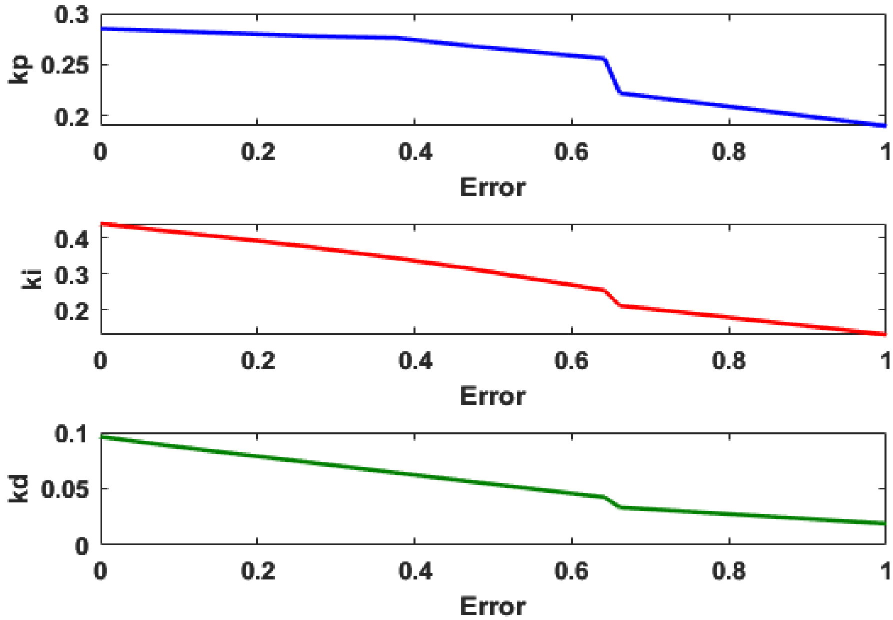

Figure 10. PID Parameters Against System Error

In Figure 10, the Parameters of the PID controller maintained their optimal values: 0.2850, 0.4410, and 0.0964 for k_p, k_i, and k_d when error (i.e. the deviation of the actual output from the setpoint value) was 0 but attained their lowest values when error is 1. The state at which the error is 1 can be regarded as the initial state of the actual output at t = 0. Thus, looking at Figure 10, it suffices to say that the effectiveness of the controller decreases as the controlled variable (i.e. actual position of the antenna) deviates further from the setpoint value (i.e. referenced position).

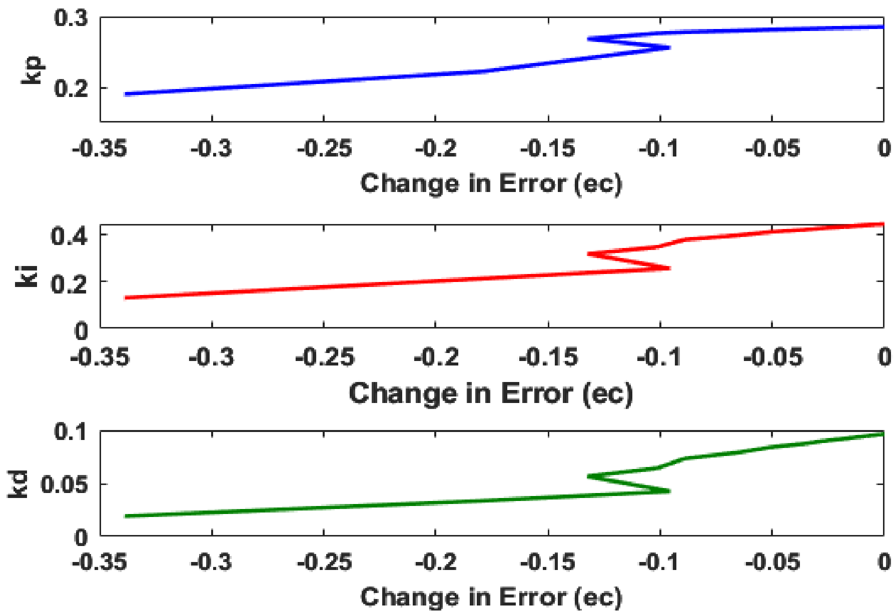

Figure 11. PID Parameters Against Change in Error

For the relationship plot in Figure 11, it can be seen that as change in error occurs due to the difference between the setpoint position and the actual position, the values of the PID parameters were low. However, after a while, as the change in error tends to 0 (at which point the actual position = the setpoint position), the values of the PID parameters are optimized. Thus, it can be said that as the control process proceeds in forward mode, the deviation of the actual position of the antenna from the reference position with respect to time approaches to zero for efficient positioning.

This is the fundament requirement of a control system designed to meet a specified setpoint value.

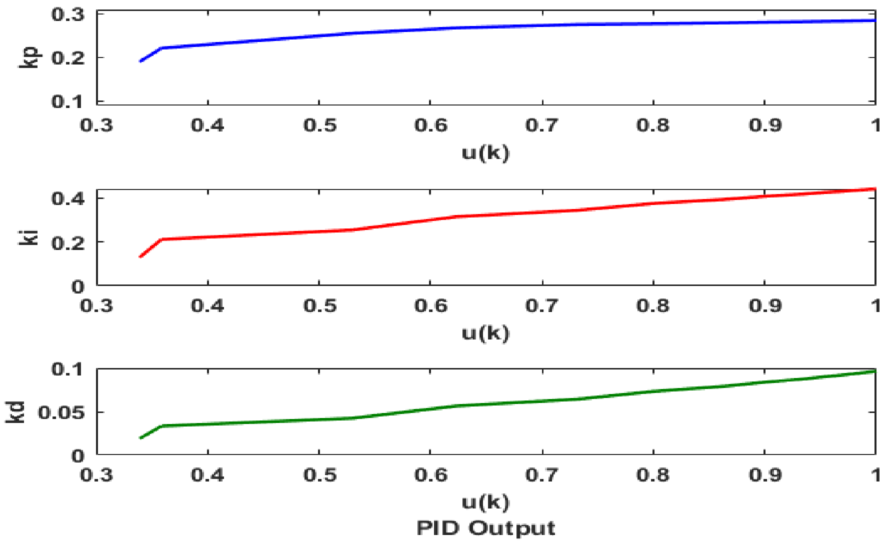

Figure 12. Plot of PID Parameters Against Control Variable

As shown in Figure 12, the values of the PID parameters increases linearly as the control command or variable (PID output) and are optimized at u(k) = 1, which agrees with the simulation plot in Figure 6. This is an indication that the control variable linearly vary partly to individual gain of the PID controller that combines together to give the needed command action to drive the antenna to desired position.

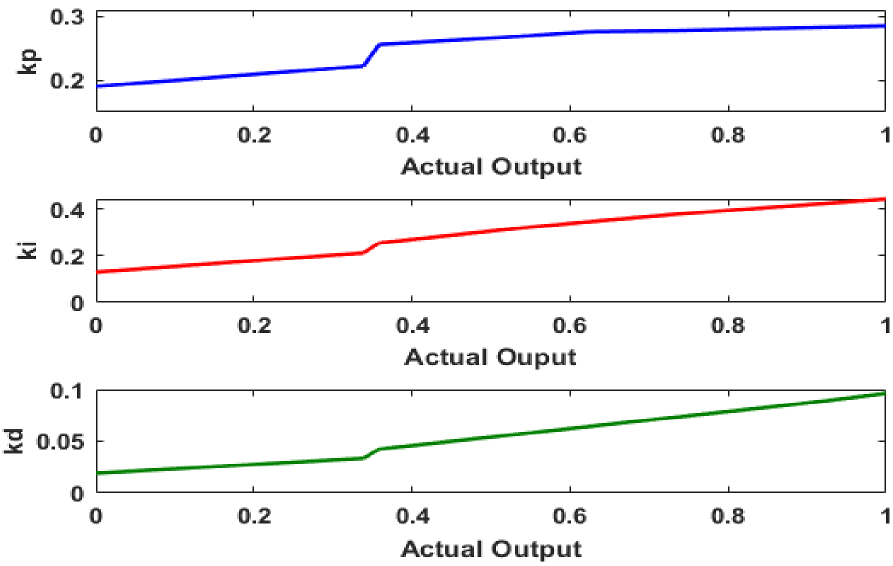

Figure 13. Plot of PID Against Target Position

The relationship between the PID parameters and the actual output, which in this case is the same as the target position (or setpoint) since the system is meant to maintain this value (i.e. unit step input), is shown in Figure 13. It can be seen that the parameters of the PID controller increases linearly until optimal values are attained when the system output attained the same value as the setpoint. Though distortion occurred at time t = 0.004 s when the system output was 0.3389, this was quickly eliminated and therefore did not influence the control command provided by the auto-tuned PID controller and the system behaviour. This is because the BPNN algorithm provided adaptive capability by ensuring that errors generated are continuously propagated back for appropriate correctional action to be performed within the loop of the control process and is able to compute and tune the PID controller while optimizing its parameters for optimal control performance using the four input variables.

3.3. Step Comparison of different Control system

This subsection presents comparison of the performances of the proposed control algorithm and the control techniques base on PID algorithm from previous studies regarding position control systems of the considered telemedicine antenna. In these studies step response performances of classical PID controller in [2] tagged PID1, classical PID plus pre-filter controller in [1] tagged PID2, and PID tuned compensators (PID-TC) in continuous time and discrete time in [3] including a discrete time PID tagged PID(z) simulated as part of this study are shown in Figure 14.

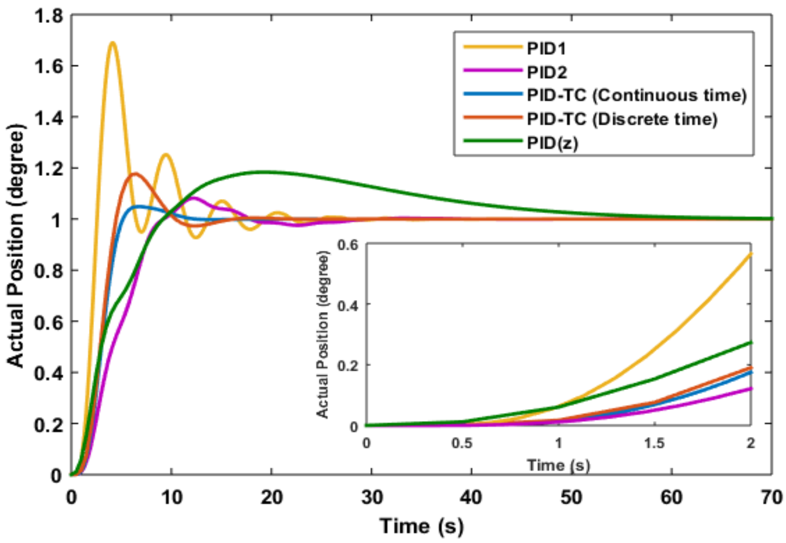

Figure 14. Comparison of Control System Output Response

The subplot inserted in Figure 14 indicates that output responses of PID1, PID2, PID-TC (continuous time), PID-TC (discrete time), and PID(z) control system where performing at very much lower value than the setpoint value even after 2 s as compared to the proposed control system (BPNN-PID). Even before the 2s, the BPNN-PID controller must have completed the control process. As a result of this, it was not possible to have good comparison plot of the output response of the BPNN-PID together with the output responses of other algorithms. Thus, the comparisons of the time domain parameters of the step response transient characteristics in terms of rise time, peak time, peak percentage overshoot, settling time, and steady state error are numerically presented in Table 3. It should be noted that the steady state error is the difference between the value of the desired input and the value of actual output.

Table 3. Numerical Presentation of Different Control System Applied in the Considered Satellite Antenna

System	**Rise time t_r (s)**	**Settling time (t_s) (s)**	**Peak time (t_p) (s)**	**Overshoot (M_p) (%)**	**Steady state error (e_{ss})**
Uncompensated	86.6	154	350	0	0
PID1	1.31	21.2	4.13	69.1	0
PID2	5.61	23.8	12.2	8.19	0
PID-TC (cont.)	2.75	10.1	6.75	4.86	0
PID-TC (discrete)	4.68	10.2	6.5	8	0
PID(z)	6.9	53.6	21	17	0
BPNN-PID	0.027	1.06	0.06	0	0

With further simulations to ascertain the effectiveness of the BPNN-PID control system in this study, its output response parameters were compared with other control systems that have been previously studied regarding positioning of antenna communicating with a base station via a satellite link for telemedicine operation. The major observations from the simulation comparison as shown in Table 3 are that the proposed BPNN-PID controller yielded the fastest response speed for the positioning control of the antenna for satellite communication in terms of reduced rise time

(0.027 s), and offers the most reduced settling time (1.06 s). The percentage overshoot of the proposed system was the same as that of the uncompensated system, but was achieved at a very much reduced peak time (0.06 s). However, compared to other control systems, it offers the best percentage overshoot (i.e. 0). Steady state (e_{ss}) was reached at the shortest time considering the settling time.

The response speed in degree per second provided by other control systems considering their individual rise time was 0.76 (PID1), 0.18 (PID2), 0.36 (PID-TC continuous), 0.21 (PID-TC discrete), and 0.14 (PID(z)) respectively. These response speeds are very much less than that provided by the designed BPNN-PID controller.

The practical implication of this performance offered by the designed controller is that it is suitable for controlling the dish antenna position and can address the problems of internal delay and mismatch or variation in system parameters which can be caused by disturbances or nonlinearity effect of operating devices. The designed controller is for a satellite antenna whose position is controlled wirelessly from a control room. In practice, the BPNN-PID algorithm will be implemented using a microcontroller as part of the installation for the control room equipment. One potential challenge to practical implementation is cost. The obvious limitation is that the system performance was only evaluated via MATLAB simulation that provides real-time analysis of systems whose dynamics have been modelled using mathematical equations and algorithms. Hence, no hardware implementation was done to ascertain its viability in practical scenario.

4. Conclusion

Control technique using back propagation neural network-based PID (BPNN-PID) model for enhancing satellite antenna positioning has been proposed. The antenna is used for sending and receiving medical information in telemedicine via satellite link. For such satellite tracking antenna, its performance quality will depend on the timing of the position control process. The model for the antenna including the associated internal delay was presented and simulation test conducted. The output response performance indicated that the system largely suffers from internal delay which prolongs the control process. The mathematical model of the antenna together with BPNN-PID controller was simulated in MATLAB. The simulation results showed that the BPNN algorithm was able to optimize the parameters of PID controller and achieved the desired output. Explicitly, the proposed controller provided good output response performance for the control system with auto-tuning of the PID controller as required, fast rise time and settling time, zero overshoot, no steady state error, adaptability to parameter variation and stability. In addition, it has been shown via simulation analysis that the problem of parameter variation can be eliminated with the use of back propagation algorithm in neural network technique. Simulation comparison with other previous position control system proposed for the considered satellite antenna proved the advantage of the proposed BPNN-PID over them. This is obvious from Table 3, where the numerical presentation of the simulation results of the BPNN-PID control system against the traditional methods revealed that it yielded rise time of 0.027 s against 1.31 s, 5.61 s, 2.75 s, 4.68 s, and 6.9 s; settling time of 1.06 s against 21.2 s, 23.8 s, 10.1 s, 10.2 s and 53.6 s; peak time of 0.06 s against 4.13 s, 12.2 s, 6.75 s, 6.5 s, and 21 s; and overshoot of 0 against 69.1%, 8.19%, 8.19%, 4.86 %, 8 %, and 17% for PID1, PID2, PID-TC (cont.), PID-TC (discrete), and PID(z) respectively. Generally, the BPNN-PID controller is suitable for high speed position control of the antenna; improve overall performance of the system while eliminating the problem of internal delay and the mismatch in system parameters which can be caused by effect of nonlinearity. Despite the performance of the designed system, further study on the BPNN-PID algorithm can be investigated by comparing it with other types of artificial neural network models and other forms of intelligent based control systems designed and applied to the considered satellite antenna structure.

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