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DEVELOPING A HYBRID OF TUNABLE PROPORTIONAL INTEGRAL DERIVATIVE (TPID) AND NEURAL NETWORK (NN) CONTROLLERS FOR VIBRATION SUPPRESSION OF FLEXIBLE ROBOT ARM MANIPULATORS

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ABSTRACT

The main objective of designing industrial robots is to carry out tasks that are oftentimes routine in nature. The designs are achieved by ensuring the manipulators to move the body, arm and wrist through a serious of motions. To ensure these motions, controllers are also designed to enhance stability and flexibility. Conventional proportional integral derivatives (PID) controllers which are most popular are not particularly efficient in providing this control operation. This work presents a hybrid of tunable PID and neural network (NN) controllers for vibration suppression of flexible robot arm manipulators. Mathematical models were developed to design the proposed hybrid. A model of the hybrid system was developed. Thereafter, different control parameters including joints and rotational angles, electrical and mechanical plant components and forearm transposition model were used to design the body, arm and wrist components of the robot manipulator. The hybrid was simulated and results show that the proposed model produced a better controller that the conventional PID or NN controller used alone for a robot arm control.

Keywords: Proportional Integral Derivative (PID), TunableProportional Integral Derivative (TPID), Neural Network (NN), Hybrid, Robot Arm Manipulators.

1.0 Introduction

Industrial robots are designed to carry out desirable works that are most times routine in nature. This can be achieved by enabling the manipulator to move the body, arm and wrist through a series of motions. The movements helps the end effectors of the robot to achieve the desirable position and orientation in the three dimensional space surrounding the base of the robot. The robot joint enables relative movement between parts of a robot arm. The joints are designed in such a way to enable the robot move its end-effector along a path from one position to another in accordance with the desired input.

Classifications of robots are based on the type of drive technology used in the design. The drive system is an important component of the robot which provides the needed power for the actuation of various linkages and joints of a robot so that the robot can be propelled or move. Depending on the type of power source, the dynamic performance of the robot can be determined. Holistically, there are three types of power sources for robots namely: electric drive, hydraulic drive and pneumatic drive. Majority of the industrial robots make use of electric drive system, in the form of either direct current stepper motor drive for open loop control system, or, direct current servo motor drive for closed loop control system. The significance of this drive system is that it provides accuracy in positioning, precision in speed accuracy and repeatability.

When higher speeds are paramount to drive substantial loads, hydraulic drive system robot are preferred. One of the shortcomings of this particular drive is that it occupies large space area and it is susceptible to oil leakage on the operating floor. Robots powered by hydraulic drive systems are mainly large sized robots while those that use electric drive system is good for small and medium size robots only. Those powered by pneumatic drive system is applied when the objective is to achieve high speed while driving high-loads. A pneumatic drive is clean and fast compared to other drives though its control is quite difficult since air is a compressible fluid. Pneumatic drives are specially deployed when the gripping action of the end effectors is merelyan open and close operation to pick and place light objects. Preference is on the pneumatic drive system for smaller robots as these are less expensive than electric or hydraulic robots and suitable for relatively less degrees of freedom design for simple pick and place application.

Two controllers (TPID and ANN) could be developed and integrated to achieve a hybrid system. Technically speaking, a hybrid system is a system that is a combination of two different things. It is a dynamical system that runs in a process by exhibiting both continuous and discrete dynamic behaviour. Thus a hybrid system can both flow and hence be described by a differential equation as well as jump and be described by a state machine or automation. The values of the continuous variables and a discrete mode are used to describe or define the state of a hybrid system. The developed hybrid controller was used to carry out real-time simulation in Simulink.The control resolution for a robot is determined by the position control system and the feedback measurement system. It is the controller's ability to separate into parts the total range of movements for the particular joint into individual increments that can be addressed in the controller.

2.0 Review of Related Works

The following reviews of related works are meant to provide insight into the current work.

Al-Shuka and Song, (2017), proposed Adaptive Hybrid Regressor and Approximation Control of Robotic Manipulators in Constrained Space. A hybrid regressor and approximation adaptive control was proposed for dealing with uncertainty of robotic systems. The idea behind the proposed controller is that the regressor attempts to estimate the known structure of the investigated system (inertia matrix, Coriolis and centripetal matrix, and gravity vector) while the approximation term of the controller estimates the unmodeled dynamics of the systems resulted from inexact calculation of regressor and other internal/external disturbances.The results show the effectiveness of the proposed controller for dealing with miscellaneous disturbances but the hybrid controller is complex.

Khoobjou and Mazinan (2017) did a work On Hybrid Intelligence-Based Control Approach with Its Application to Flexible Robot System. Robots are taken into real consideration due to their application in academic and industrial environments. To predict and optimize the overall robotic performances, a number of soft computing techniques could be preferred with respect toconventional ones. In order to enable the process under control to be capable of learning and adapting to be matched, in a number of real environments, the proposed fuzzy-based approach was proposed. A new hybrid approach was proposed to deal with the arm of flexible robot system through the neural networks, the fuzzy-based approach and also the particle swarm optimization. The proposed research was aimed at controlling the claw of robot system including two-degree-of-freedom movable arms. Results indicated that the mean-square error and the root-mean-square error were accurately outperformed with reference to the traditional ones.

Khoobjo (2015) did a work titled, New Hybrid Approach to Control the Arm of Flexible Robots by using Neural Networks, Fuzzy Algorithms and Particle Swarm Optimization Algorithm. In the work, the author was of the opinion that one ofthe mostimportant and widespread fields which was used inthe processes of production and controlwas instruments mechanization. Inorder to predict the performance of processes and optimize them, soft computing methods based on physical models have been preferred to common methods due to the complexity and distrust of processes of mechanization. A hybrid of fuzzy logic and neural networks enables the system to have the capability of learning and adapting to the environment, as well as tolerating the imprecise circumstances which is an advantage of fuzzy logic methods. A new hybrid approach was proposed for flexible robot arm control by using neural networks, fuzzy algorithms and particle swarm optimization algorithm. Control of robot’s claw with two movable arms was the objective which was achieved.

In the reviews carried out, the need for hybrid controller application in robot arm manipulators to achieve improved precision was established. This has buttressed the obvious need for this work. The procedure for achieving this phenomenon is presented in the next section.

3.0 Methodology

The methodology in the development of the desired hybrid is described at this point of this report.

3.1System Implementation

- **System Description and Materials**

Figure 3.1 presents the kind of robot arm to be implemented. The figure shows a6DOF manipulator, which is a serial chain control system consist of several modules and gripper end effector that is interconnected by six revolute joints.

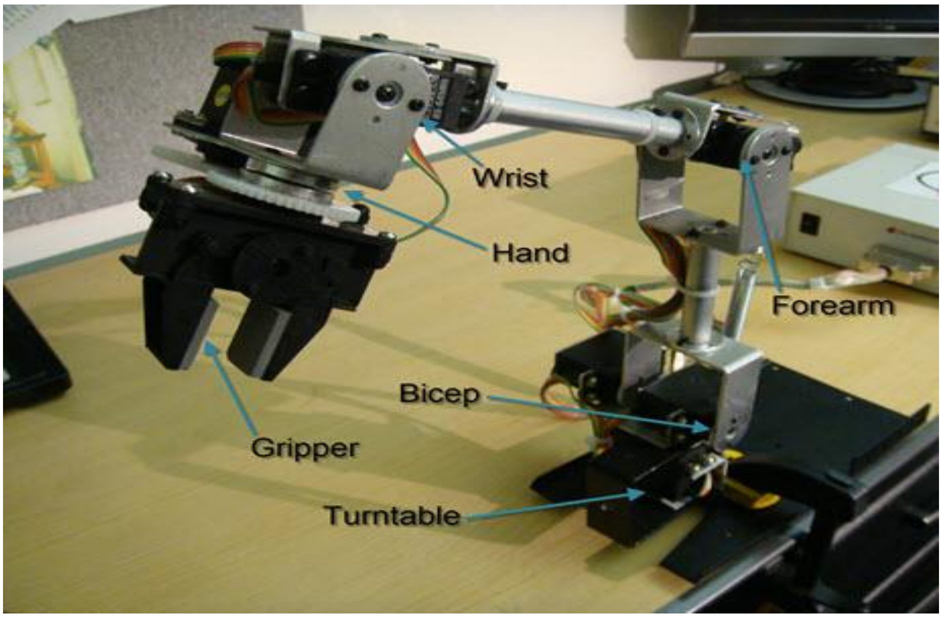

Figure 3.1: Robotic arm with 6 degree manipulator (Mathworks, 2018)

Those modules mentioned contained an inbuilt brushless servomotor capable of delivering the expected torque. The modules also contained incremental encoders for positioning and speed control with fully integrated power and other components.

- **The hybrid of NN and PID Controller**

The hybrid control system was designed based on system requirements. It was based on compensation between the NN controller and the PID controller. The neural network is employed to compensate for the PID shortcomings such as saturation, aggressiveness, settling time, backlash and so on, using its adaptive capabilities in order to ensure system stability and performance efficiency.

The hybrid model was developed by simple integration using an integrator. The Simulink model was developed using appropriate blocks.

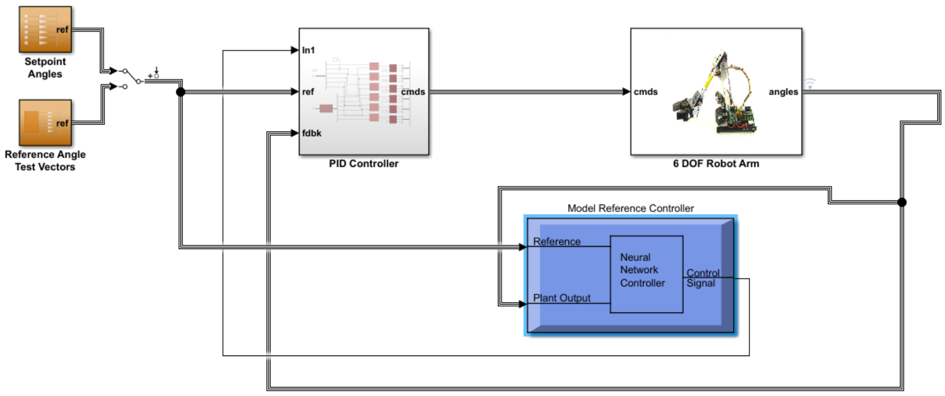

Figure 3.2: The developed hybrid system

System Description and Materials

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➢ Manipulator Joints

This is the part of the manipulator where two or more links are connected together; many kinds of joint can be made between two links as shown in Figure 3.1. However, only two basic types are commonly used in industrial robots which are the revolute (**R**) joints and Prismatic (**P**) joints. In case of revolute joints, two links are joined by a pivot about the axis of which the link can rotate with respect to each other, while in the prismatic joints, two links are so connected that they can slide (linearly move) with respect to each other.

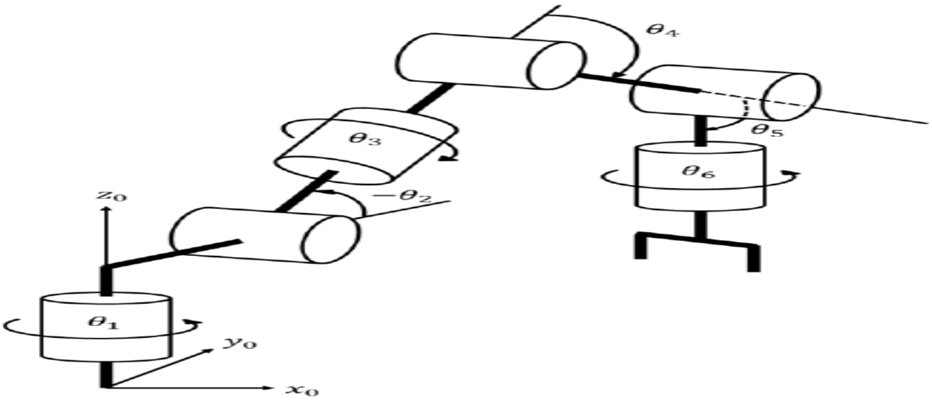

Figure 3.3: Robotic arm displaying joint and rotational angles

- **DC Motors**

DC motor as in Figure 3.1 consists of a **stator** and a **rotor** that rotates relative to the stator as a result carries the frames of the manipulator to different position and orientations using torque. It creates torque by sending current through windings in a magnetic field created by permanent magnets, where the magnets are attached to the stator and the windings are attached to the rotor, or vice-versa (Yushuand Zhihui, 2013).

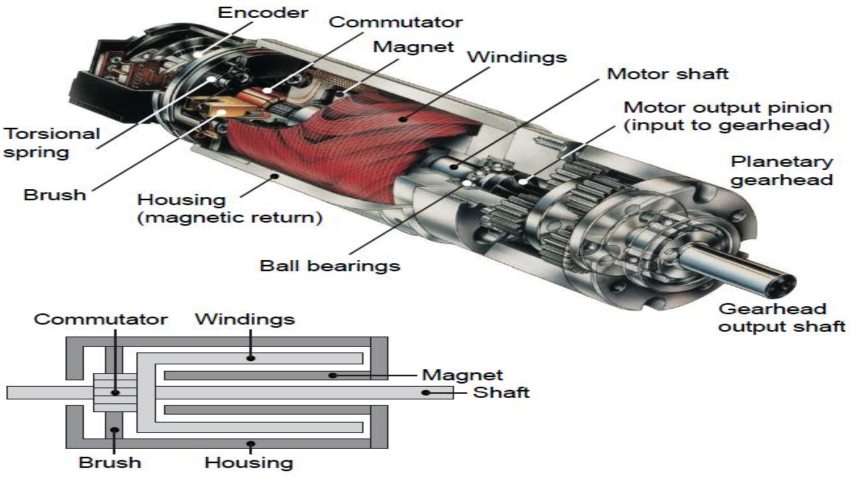

Figure 3.4: Brushless DC motor (Yushuand Zhihui, 2013)

The DC motor windings which are energized and some of which are inactive at any given time are chosen as a function of the angle of the rotor relative to the stator (Mata et al., 2015). This "commutation" of the windings occurs mechanically using brushes (brushed motors) or electrically using control circuitry (brushless motors) (Ngoc et al., 2009). This work employed brushless motors with the advantage of no brush, wear and higher continuous torque, since the windings are typically attached to the motor housing, the heat due to the resistance of the windings can be easily dissipated.

- **Degree of freedom (DOF)**

The number of independent movements that an object can perform in a 3-D space is called degree of freedom (DOF). The proposed system is required to rotate in all directions. Thus, the manipulator with 6-DOF is expected to point any position and orientation.

- **Manipulator End effector**

This is the part that is connected to the last joint of a manipulator which generally handles objects, makes connection to other machines, or performs the required task. These can be grouped into two major categories: Grippers and Tools.

Grippers are to grasp or hold the work piece during the work cycle in the industry. The proper shape and size of the grippers and method of holding are determined by the object to grasp and task to perform. Grippers employ mechanical grasping or other alternative way like magnetic, vacuum, bellows for holding. For many tasks to be performed by the manipulator the end-effector is used as tool rather than gripper for multi-purpose task like, cutting tool, drilling, welding torch, spray gun or screw driver is end-effector for machine.

The hybrid mode shown in Figure 3.2 is made up of two main sections, which are the controller and the 6DOF manipulator mechanism to be controlled as shown in figure 3.4.

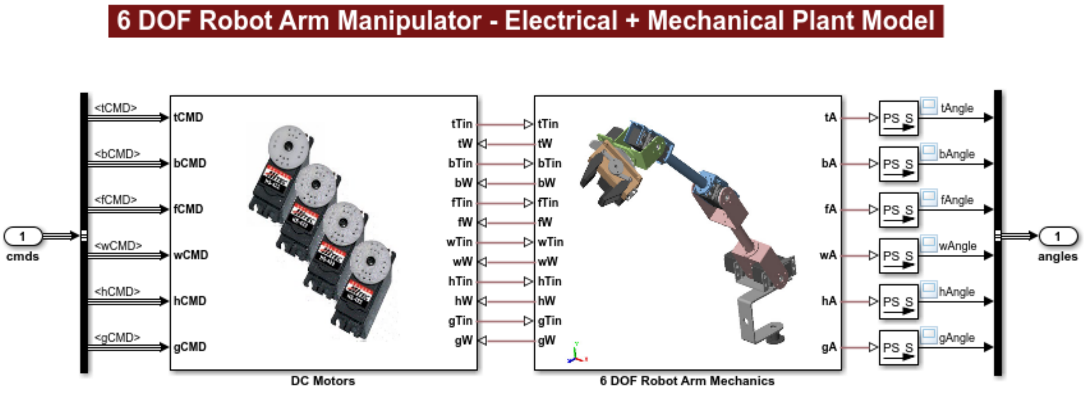

Figure 3.5: The electrical and mechanical plant component

The manipulator mechanism was implemented using Simscape components representing the parts assembled in Figure 3.4; This parts are end effector (g), the forearm (f), the wrist (w), the base (h) and the bicep (b).

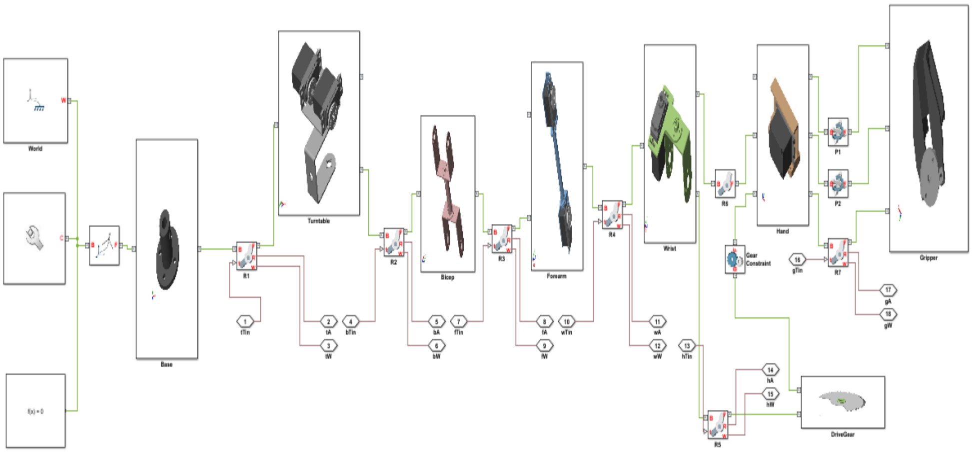

Figure 3.6: Assembly mechanism of the manipulator

The manipulator mechanisms(Figure 3.6) are designed and connected to each other with the ability to revolute at various transposition parts, starting with the end effector (g) (Figure 3.7), the forearm (f) (figure 3.8), the wrist (w) (figure 3.9), the base (h) (figure 3.10) and bicep (b).

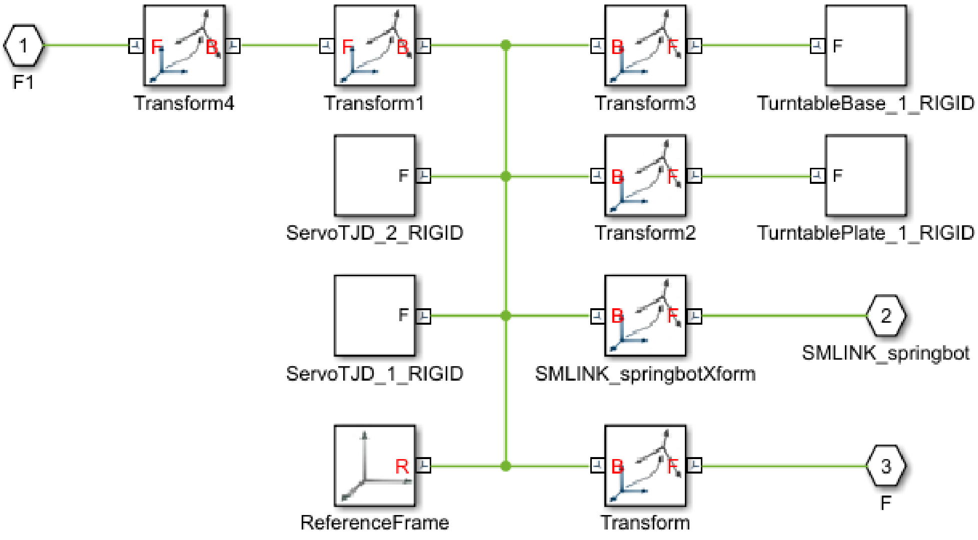

Figure 3.7: The tunable control mechanism

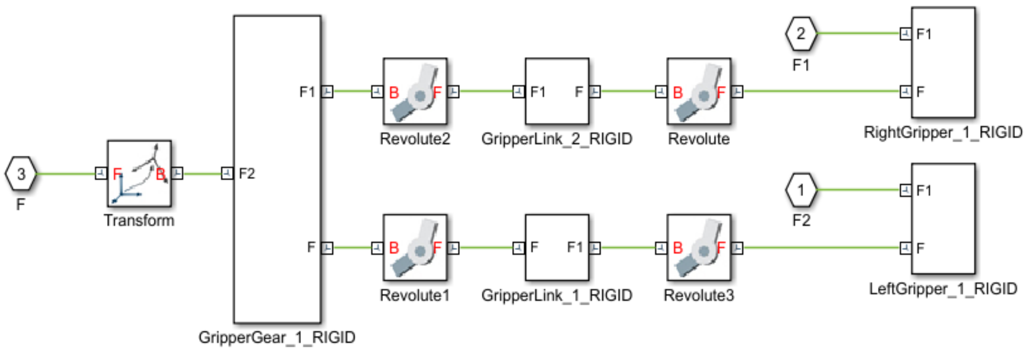

Figure 3.8: Mechanism of the end effector (gripper)

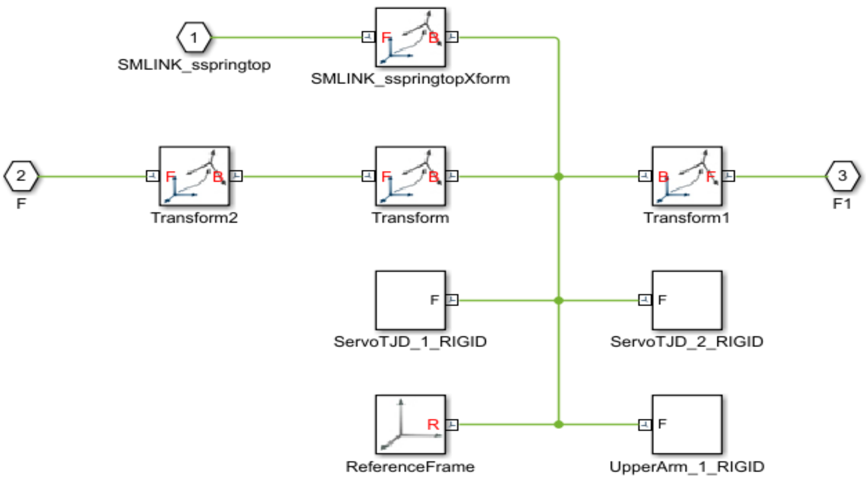

Figure 3.9: Transposition model of the forearm

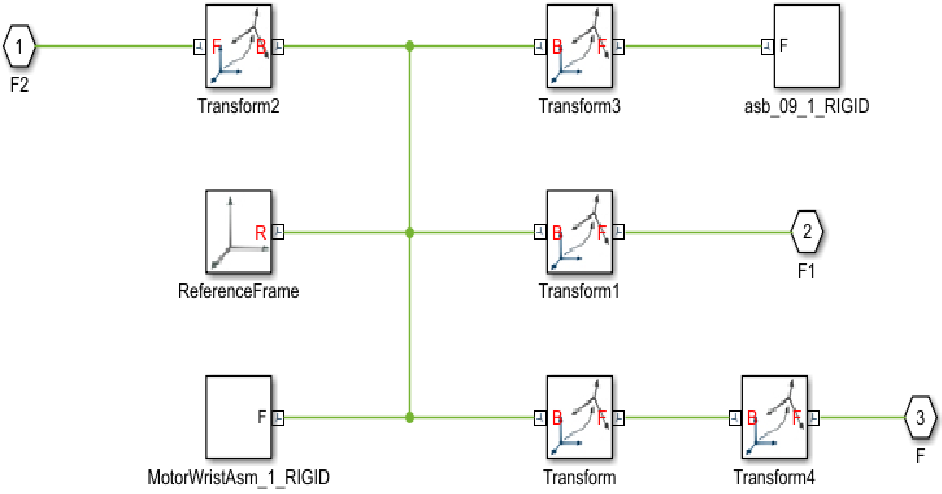

Figure 3.10: Transposition of the wrist

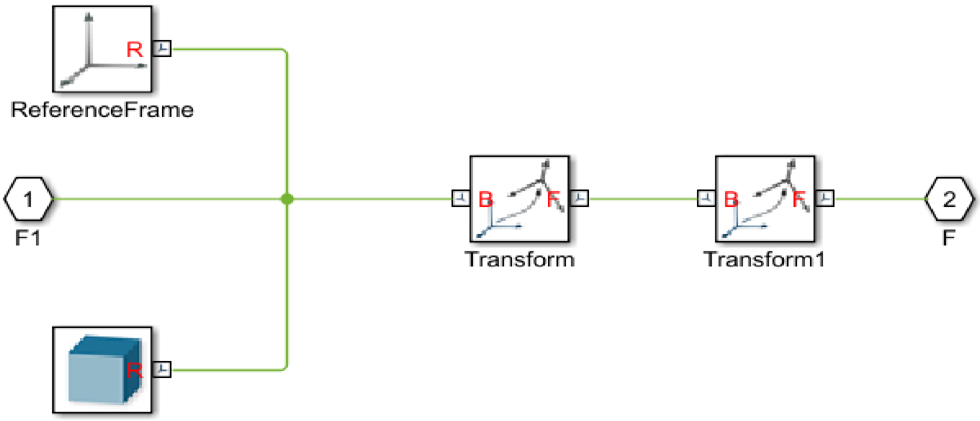

Figure 3.11: Transposition model of the base manipulator

Figure 3.12; presents the connection chain of the brushless DC motor to the manipulator joints, each of this joints are tunable and separately connected to its own motor, except for the bicep which has two DC motor.

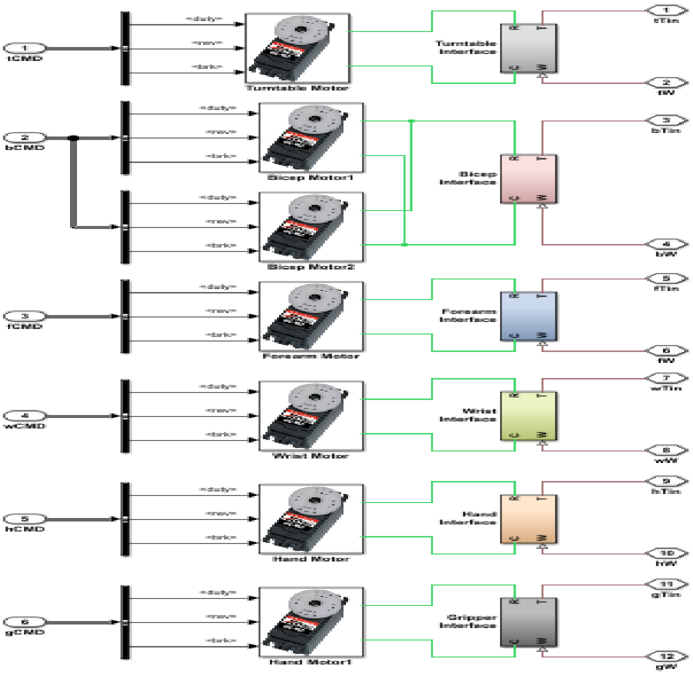

Figure 3.12: The connections chain of the brushless DC motors to the manipulator joints

The configuration setting for each of the joints reference angle test vector and the set points angles are presented with Figures 3.13 and 3.14 of which the results will be discussed in chapter four.

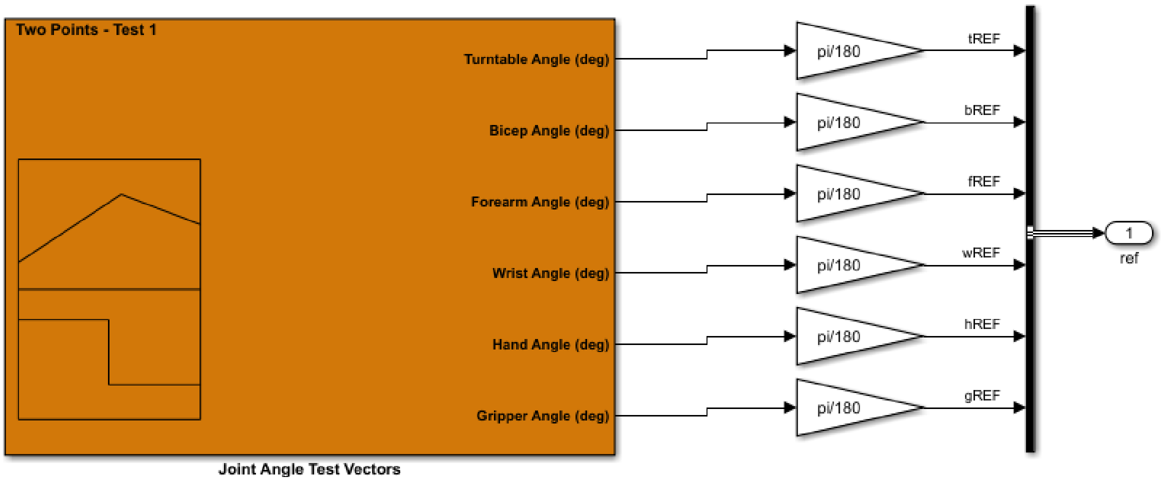

Figure 3.13: Configuration of reference angle test vector

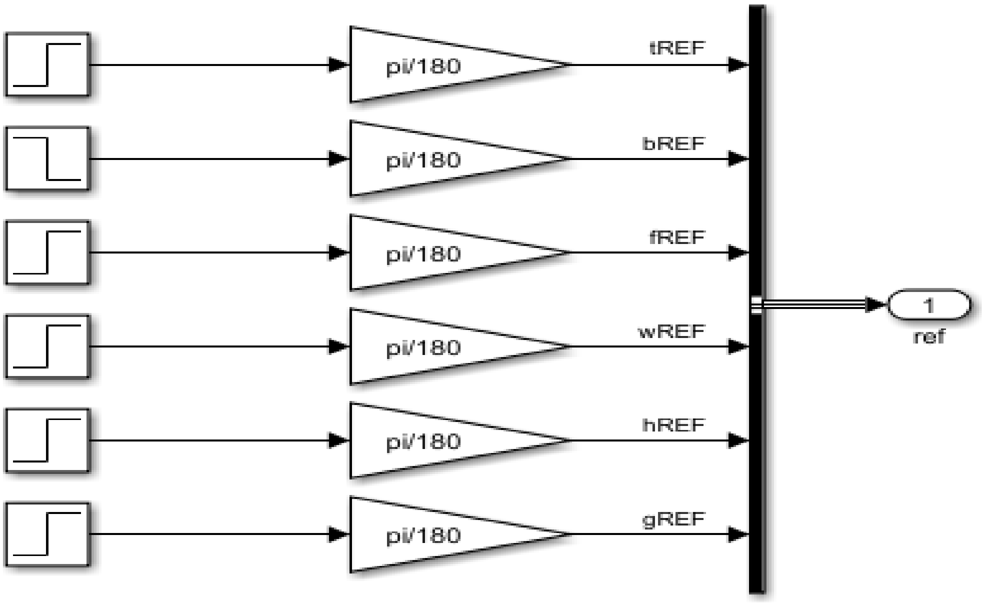

Figure 3.14: configuration of the set point angles

The other main part of the simulation model (Figure 3.14) is the hybrid (PID and Neural Network) controller section which connects each joint in Figure 3.15. This hybrid controlling technique is employed for both controllers to complement each other.

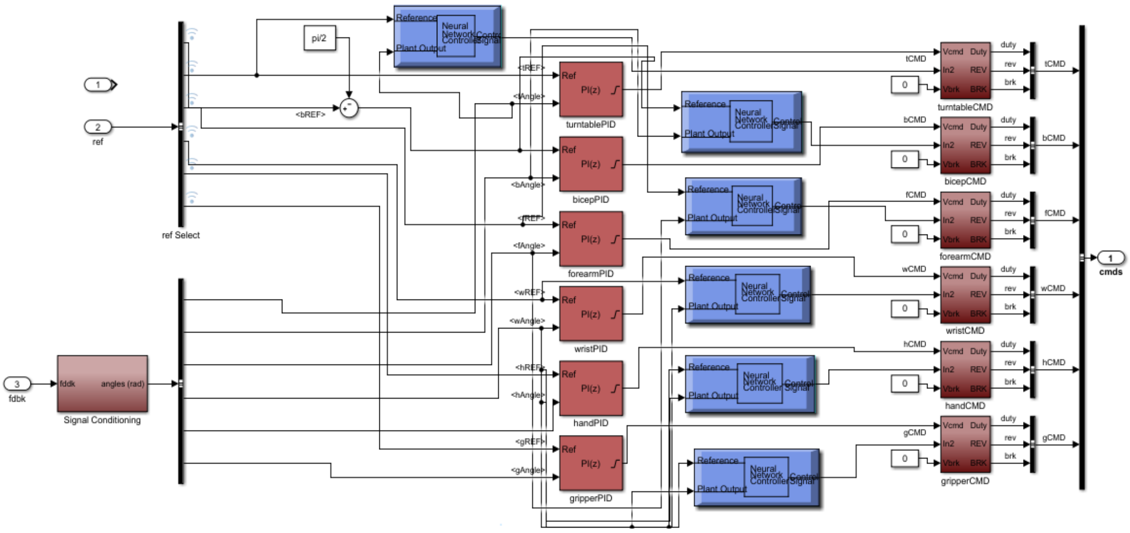

Figure 3.15: Connections chain of the hybrid controllers to the manipulator's joints

The PID controller gain can be varied for each joints (see Figure 3.16) to help cancel external disturbance. The software tuning method used for the PID controller design incorporates a tuned control filter (Figure 3.17) to help achieve the good disturbance rejection and faster settling time.

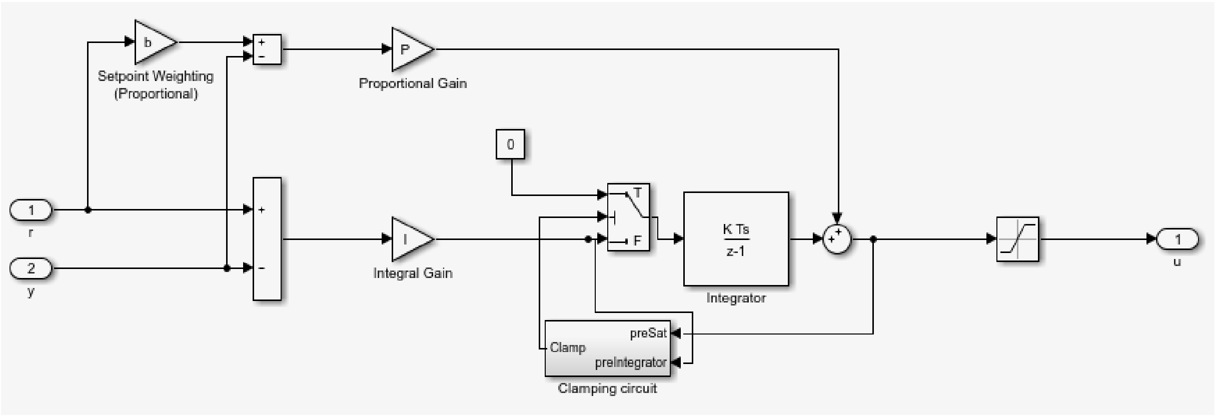

Figure 3.16: Tuning configuration for the joints

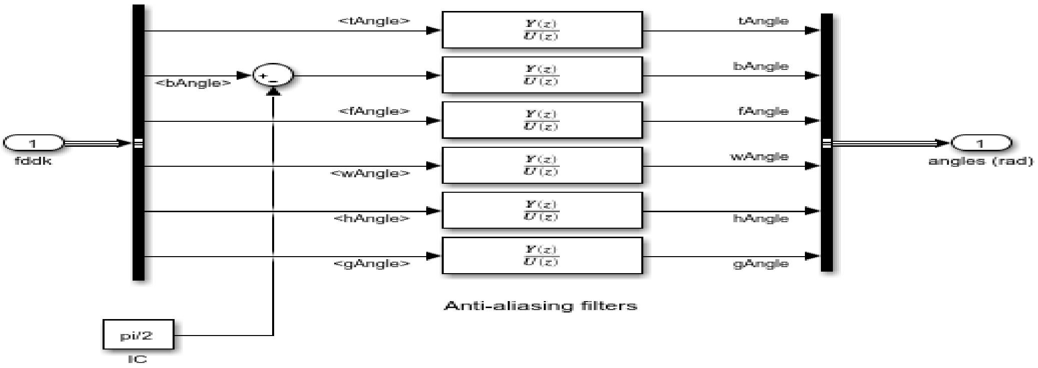

Figure 3.17: Tuned controller filters

The model of the two brushless dc motor for the bicep control is presented in Figure 3.18 which is powered by a deserved torque and current that will be discussed in chapter four.The overall architecture and operability of the system is summarized using the block diagram, presented in Figure 3.19, which shows the feedback controlled PID and Artificial Neural network manipulator at a sampling time cycling through a period until the overall behavior is satisfied. The manipulator moves at a particular configuration in a given time series in seconds with the smooth angular velocity at each joint exactly like the one in table 3.3 (Eneh, I. I., 2005).

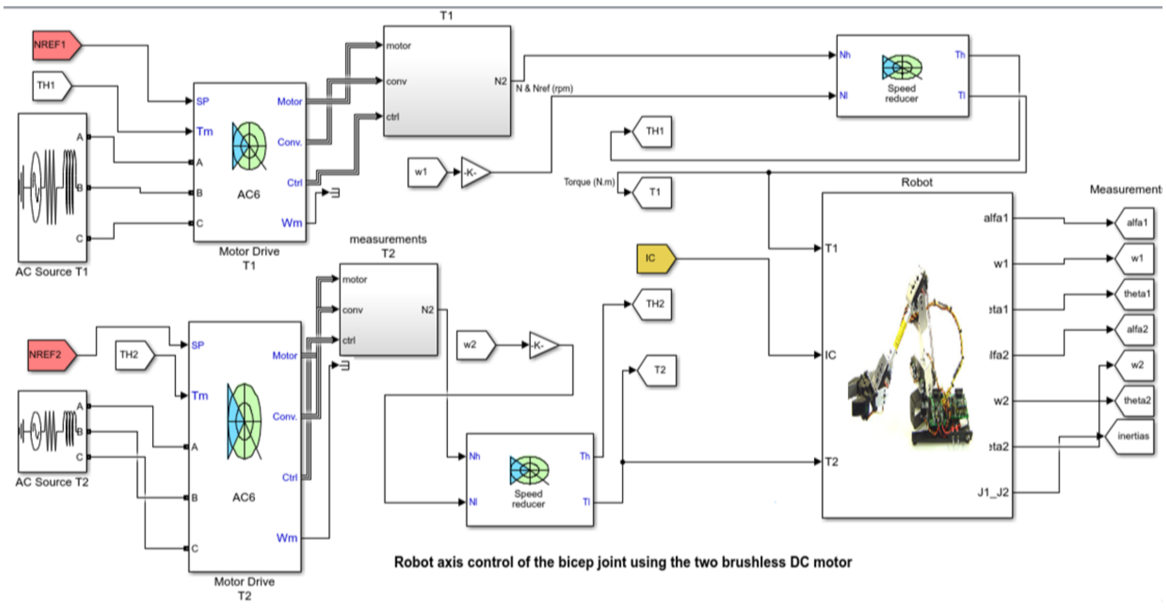

Figure 3.18: Robotic end effector or gripper control with two DCmotor

This proposed hybrid controller system was finally implemented using Simulink, Control system toolbox, Robotic system toolbox and RobotOperating System (ROS) to create the desire model of the manipulator system control with the provided joint parameters of table 3.1.The complete system diagram is shown in Figure 3.19

Table 3.1: Manipulator joint configuration

Number of joints	**Number of dc motor per joint**	**Angles (degree)**
Angular position (t)	1	60
bicep (b)	2	10
Forearm (f)	1	60
Wrist (w)	1	90
Hand (h)	1	90
Gripper (g)	1	60

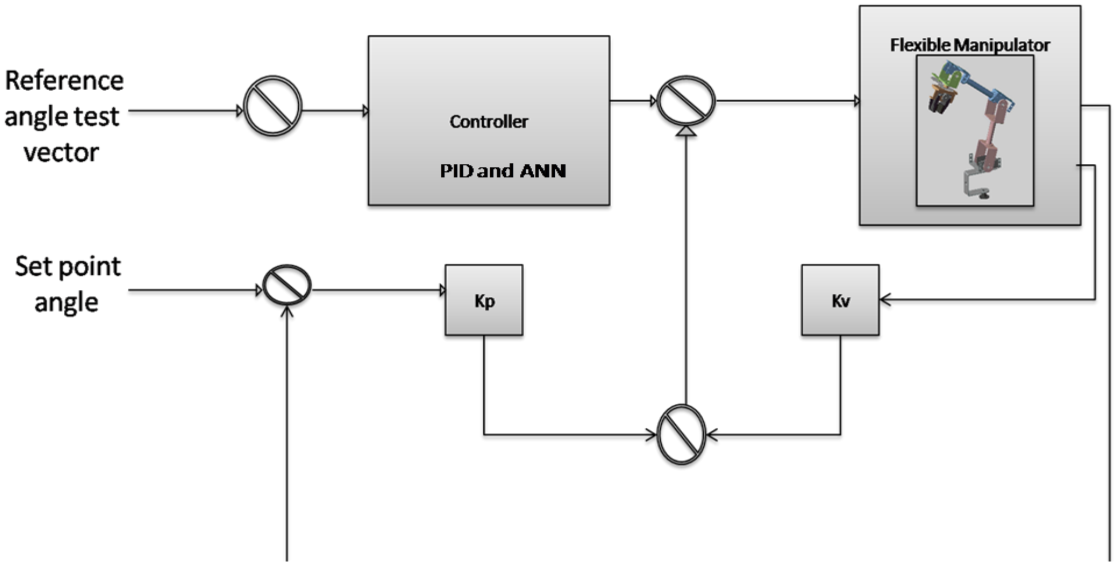

Figure 3.19: System block diagram

4.0 Presentation and Analyses

Results of simulations carried out to show the need for the developed hybrid as carried out in this work are presented and summarily analyzed. These simulation results are shown in various figures and subsequently analyzed.Also, the simulation parameters were presented in table 4.1.The purpose of this simulation was to determine accuracy and time-response of the developed systems.. According to Okafor et al., (2017), time response is the time behavior of the system when its input was changed from zero to a positive or negative value. The essence of this is to determine the stability of the developed system and its ability to reach one stationary state when starting from another. The manipulator (robot arm) was excited with step input with consideration of voltage and current rating.

Table 4.1: Simulation parameters

Number of controller	6
Control sampling time	10s
Frequency	10Hz
Total number of dc motors	9
Number of joints	6
input voltage	± 5 V

To evaluate the performance of the robot arm, it is paramount to evaluate the linearization of the various joints of the manipulator. From the simulation result, Figure 4.1 showed the resultant effect of the PID controller linearized for each joints. It can be observed from the figure that there are lots of variations along the linearized dynamics of the six joints (Eneh I. I., 2012).

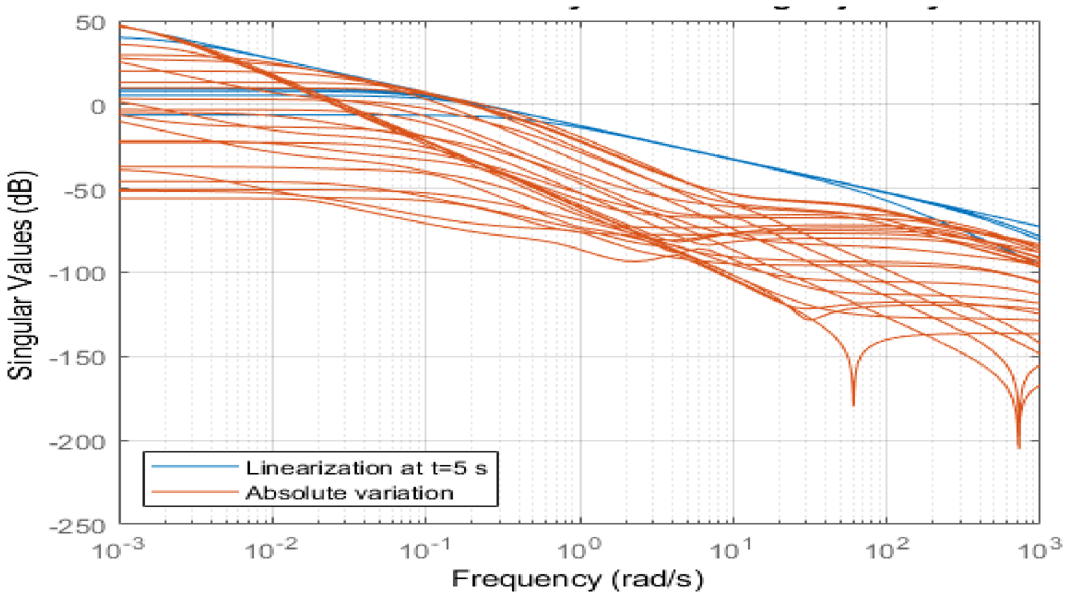

Figure 4.1: Variation of linearized dynamics along trajectory

Now, what is needed is an adaptive controller that can make the target (output) voltage to follow the reference (input) voltage. However the neural network controller has the capability to compensate for the voltage overshoots and ensure system stability. So, the hybrid controller was used instead in this case to handle that nonlinear nature of the robot arm and a linearized response for the manipulator is as shown in figure 4.2.

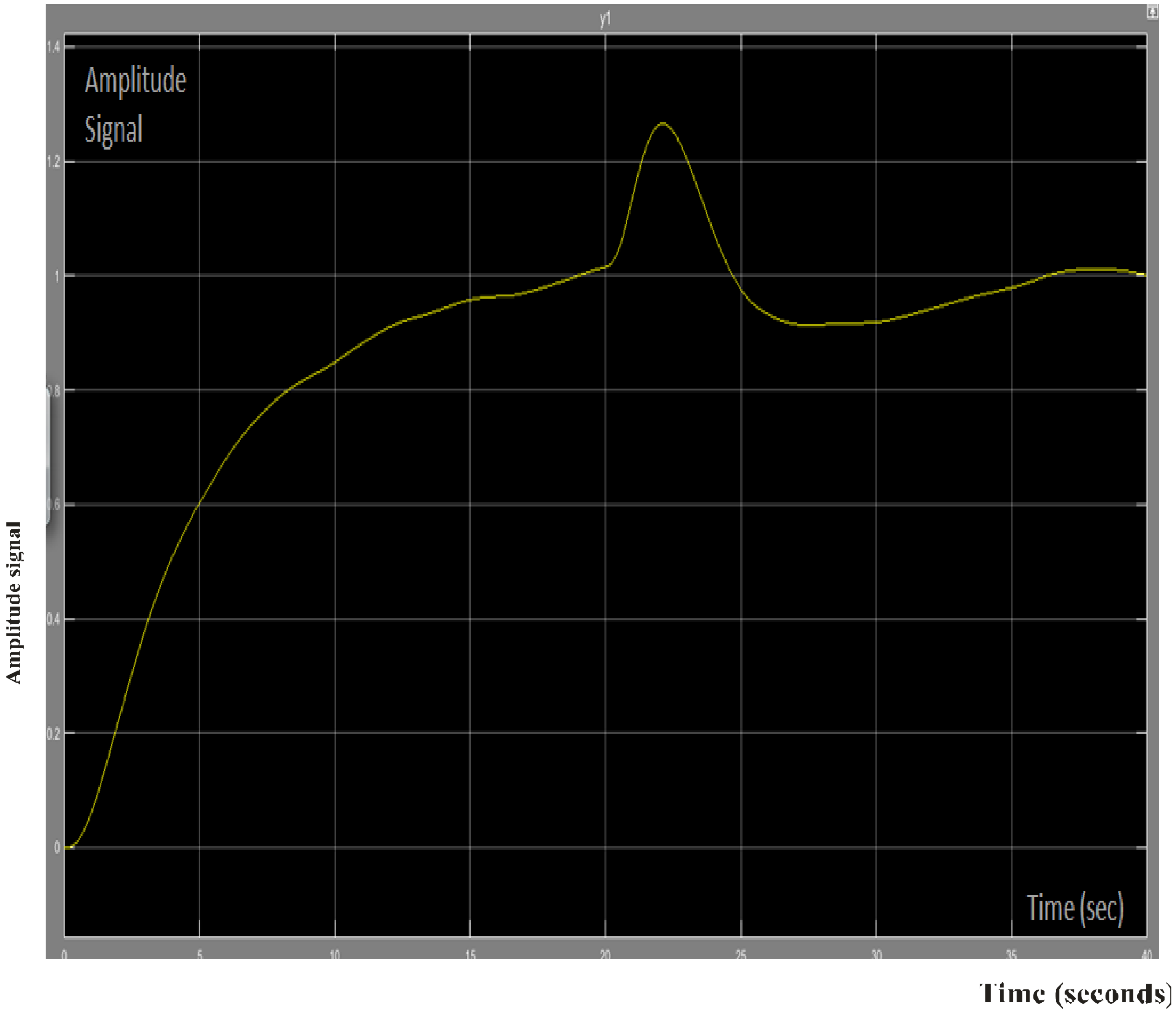

Figure 4.2: Linearized hybrid controller result of the manipulator

Time Response of the System

The essence of using time response as a determinant is to evaluate the effectiveness of a particular controller to determine the settling time. The settling time is how fast the system can achieve steady state, which is very vital in a real-time control systems and processes.

As shown in figure 4.13: The bicep response is now in-line with the other joints in terms of settling time and smooth transient, and there is less actuator saturation. Now that the steady state and homogeneous settling time have been achieved for all joints, the robot arm must move to a particular configuration with smooth angular motion at each joint in every two seconds. The robot arm is expected to start in a fully extended vertical position with all joints angles at zero except the bicep angle at ninety degrees. This result is achieved and reported in figure 4.14, showing how all the joints starts translation from the principal axis except for the bicep which translates at 90 degree (this is because bicep is controlled by two dc motors) on like the other joints. The result presents the angular translation at every 2 seconds as expected with their respective end configuration specified by the angular positions: tunable = 60 deg. Bicep at 110 deg. Forearm = 50 deg. Wrist =90 deg. Hand = 0 deg and Gripper = 0 deg.

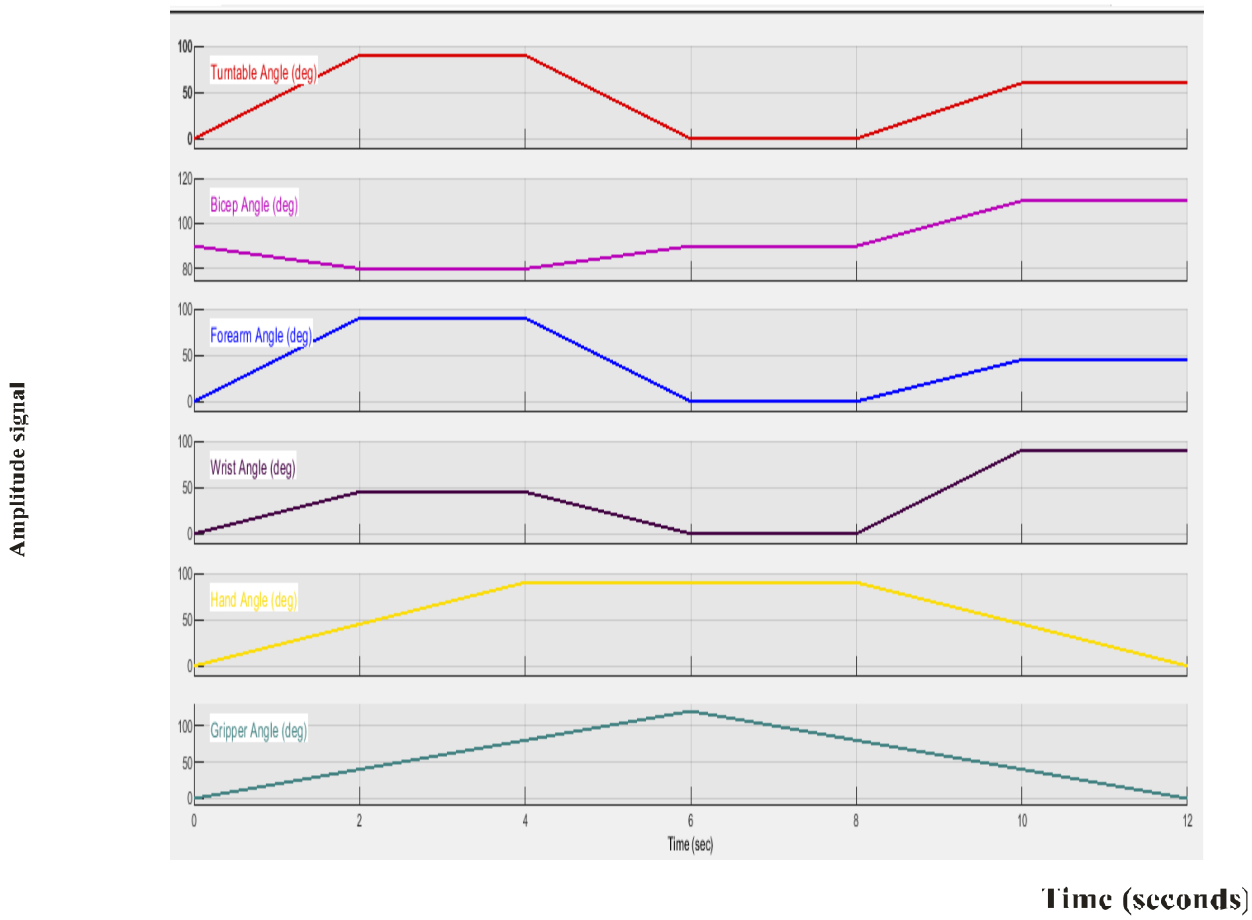

Figure 4.3: Result of the reference angle test vector

To achieve this speed control and positioning explained in the previous figures within this chapter; the dc motor drive mechanism was designed using a four quadrant speed reducer and control chopper as shown in figure 3.16 (see chapter three) to control the speed and position of the dc motor in all angular configurations.

Previously, the evaluation of the time response of the manipulator was done at joint level. Now, it is important to evaluate the time response of the robot arm as a system, to determine its response to a step input. Since the objective is to achieve stability by eradicating vibration then, position is the controllable parameter. Position here is presented in terms of angular displacement. Values of position input ranging from 10 to 180 degrees were used. Input value of 160deg was arbitrarily chosen. The result was plotted as shown in Figure 4.3.

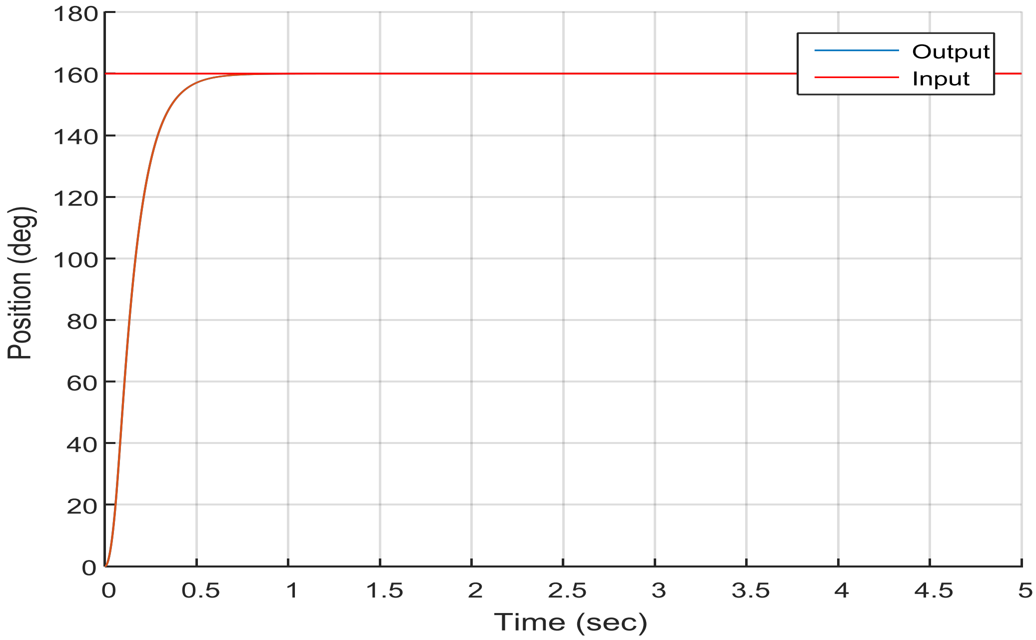

Fig 4.3 Step Input (160 degrees) Response of the Hybrid Controller

It can be observed from the figure that the proposed system target output closely followed the reference input. It was observed that the developed system achieved settling time at 0.52 sec**.** From the graph also, the percentage overshoot was calculated to be 0%.The implication of these results is that the output of the proposed system was able to reduce the system control error and accommodate nonlinearities associated with the robot arm.

5.0 Conclusion

This work is developed using two controllers, the artificial neural network and PID controller. The idea of introducing the hybrid technique is for the both controllers to complement each other in achieving the best control result for the manipulator.The hybrid controller achieved a faster settling time at 0.52sec without overshoot, which is a 78% improvement from conventional PID controller when simulated in a Simulink environment. It can be concluded that the developed hybrid system was found to accommodate nonlinearities (overshoot) associated with robot arm and still maintained good control and stability within the least possible time which was a major drawback for the conventional PID system. Future work will focus on a neural network and fuzzy combination in the control of robot arm manipulator for improved result.

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