

Antenna Position Control System, Simulation and Real-time Study

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Antenna Position Control System, Simulation and Real-time Study

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May 27, 2016

Supervisor's Certificate

This is to certify that the work presented in this dissertation entitled "*Antenna Position Control System, Simulation and Real-time Study*" by "*Abdullahi Abu Obaida Mohammed Alkhalifa*", Roll Number 214EE1006, is a record of original research carried out by him/her under my supervision and guidance in partial fulfilment of the requirements of the degree of *Master of Technology in Electrical Engineering*. Neither this Thesis nor any part of it has been submitted for any degree or diploma to any institute or university in India or abroad.

K. Ratna Subhashini

Dedication

This work is dedicated to:

My Father,

My Mother,

Mohammed,

Hozaiifa and Sisters

Declaration of Originality

I, Abdullahi Abu Obaida Mohammed Alkhalifa, Roll Number 214EE1006 hereby declare that this dissertation entitled "*Antenna Position Control System, Simulation and Real-time Study*" represents my original work carried out as a postgraduate student of NIT Rourkela and, to the best of my knowledge, it contains no material previously published or written by another person, nor any material presented for the award of any other degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the thesis. Works of other authors cited in this thesis have been duly acknowledged under the section "Bibliography". I have also submitted my original research records to the scrutiny committee for evaluation of my thesis.

I am fully aware that in case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present thesis.

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Acknowledgment

It was great times here in NIT Rourkela, despite of the difficulties I have faced but the support of my special people made them easy. I would like to express my warm gratitude to one of the most smiling, optimistic and friendly personalities I have met; my great supervisor (*Subhashini*). Despite of that the area am working in is somewhat away from her field but whenever I have faced any difficulty she would have used her knowledge along with her wisdom to find out a solution.

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My family is the source of motivation through which am getting the power to move forward, they are always happy to my good things more than me.

And I should say Thanks to Allah (*Alhamdulillah*) before and after; without him I am nothing.

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Abstract

Antenna pointing angle is the core of the quality of the transmitted/received signal. Since most of the antennas work in an outdoor environment, their pointing angles might be subjected to different types of disturbances- specifically wind gust- that might deviate them from their correct positions. The process of the position re-correction might be difficult especially if this is done manually due to the precision needed, and sometimes the location of the antenna, as well as its size, are another challenging issues that make the manual correction more difficult.

This work is a study and design of a control system that can carry the antenna to the required position as well as fix it on that position by resisting the disturbances. The resistance and the removal of the effect of disturbances require a closed loop control system and application of control algorithm (The one that is used here is Proportional-Integral-Derivative (PID) controller).

The total work is a simulation and real-time prototyping implantation of an antenna control system that is made of two motors to drive the azimuth and elevation subsystems. An Arduino Mega 2560 board is used as a controller through which the PID control algorithm and the other control commands will be performed. The system is programmed graphically through Simulink, and it is exploiting a PC as an interfacing tool to pass the command from and to the Arduino controller.

Keywords: Antenna; Azimuth; Elevation; Proportional-Integral-Derivative (PID); Arduino; Simulink

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Chapter 1

Introduction

1.1 Overview:

The precision of the position of the antenna is very crucial in the strength of the transmitted and/or received signal to/from the receiving/emitting source [21]; if the antenna deviates from the exact pointing direction this will lead to a loss or to a weakness in the transmitted and/or received signal, which will affect the entire performance of the communication system.

Most of the home TV antennas are located in relatively high places i.e. roof of the buildings; so that if any type of mechanical disturbances is imposed on these types of the antennas, that will cause the signal to be totally lost or weakened, which leads to loss or breaking of the TV channels. The readjustment seems to be difficult because it requires facing the TV screen in order to know whether the signal captured back or not; that is above the difficulty of manually finding the precise angle of the antenna.

In case of absence of any type of automated control system, the manual correction will be the only available option, which is totally impractical especially in case the antennas of big sizes, such as telescope antennas whereas their manual readjustment is difficult due to their heavy weights; or the antennas of small sizes which would also be difficult in terms of precision due to their small apertures. For these reasons the usage of the control system is essential; but the control system itself varies from open loop to enhanced control systems using different types of controllers. Here in this study, the PID controller is applied.

Since the system of any outdoor antenna is subjected to different types of torque disturbances such as wind pressure and gust [4]; the main task of the control systems is to remove or reduce the effect of such disturbances and maintain the system in its correct position.

The antenna pointing direction composes of two angles which are the azimuth and elevation angles. The azimuth angle is a horizontal clockwise rotation (toward the east) measured from the geographical north to the point that meets the projection of the satellite path on the

horizontal plane [1, 19], and it would cover a range of 360 degrees. The elevation angle covers the region between the horizontal plane and the satellite path [1, 19], which is of value up to 90 degrees.

In this study a prototype of position control system for a parabolic antenna has been designed by exploiting two motors to move the azimuth and elevation subsystems; the design is using Arduino board as brain to control and facilitate the commands and feedbacks to and from the subsystems. The precision of locating the position of the antenna and the resistance of the disturbances to which the antenna system might be subjected are the main tasks of this study, so that the application of a control algorithm is the backbone to fulfil the study objectives.

The PID controller is applied and its parameters are estimated after finding out the mathematical models of the azimuth and elevation subsystems, and that has been done after a process of data acquisition performed by the help of Matlab/Simulink software.

1.2 Problem Statement:

The disturbances that outdoor antenna might be subjected to, which cause the deviation of the antenna from the desired position, and the process of driving it back precisely are the main challenging issues of the control system designed for such a purpose.

1.3 Objective:

The objective of this project is to design and fabricate an antenna control system that has the ability to drive the antenna towards its required position as well as holding it stable on that position by providing a high resistance to any external sources of mechanical disturbance.

1.4 Structure of the Thesis:

Chapter one gives an introduction about the work of this thesis, with the body of the chapter, an overview along with the problem statement, objectives are discussed.

The literature review related to the subject of the project has been discussed in chapter two by providing brief ideas about most of the relevant topics.

In chapter three, a methodology based on which the project is implemented is covered, through which the system concept, design, and implementation are explained. The chapter

tells the mechanism of the system and the steps of its design starting with the simulation process to visualize the system and ending by how the real-time system is made.

System Modelling and Control Design is the title of chapter four; system modelling means the mathematical formula that represents the system mechanisms and makes it possible to run the system simulated version in Simulink environment. After that the chapter provides the process through which the PID controller is design, where its parameters estimation was the result of that.

Chapter five discusses the results of the simulation and real-time operation of the system. The chapter displays and comments on the results of both versions of the system, and ending by plotting the results combined in one graph for each case to give a comparative vision between the systems.

The thesis is concluded in chapter six. A part of that, the future work and the development that can be performed on the project are also discussed as well.

Chapter 2

Literature review

2.1 Antenna Position Control System:

The antenna position control system is an embedded system with electromechanical assembly [23]. The antenna control system is essential in fixing the antenna in the desired pointing angle which depends on many factors such as the type of actuator, control algorithm, the type of antenna of which the position is to be controlled and many more factors.

Different types of actuators can be used for tracking the desired position of the antenna; among them, the most commonly used is DC motor [4, 10, 17, 20, 23] with a feedback as potentiometer or encoder to read the actual position of the antenna.

To configure a complete servo system a microcontroller is needed to compare the desired and the actual position of the antenna and do the necessary correction according to the control algorithm used. Different types of control algorithm can be used including classical and modern control methods; the mostly used algorithm is the proportional-Integral-Derivative (PID). Mainly the studies published in this filed come as a study of one control algorithm or comparison between two or more control algorithms [4, 10, 20].

2.2 DC Motor and Control Purposes:

DC motors are of wide use in control purposes starting from toys, robotics, and portable tools till electric cars, lifts, and other heavy equipment. The beauty of the DC motors being in the usage the DC current which gives stable operation and very good control in terms of position, direction, exact speed control, and high torque requirements which are available with less efficiency in AC motors [8]. To impose position or speed control on DC motor a configuration called servo system is needed, which is a combination of the motor itself attached with speed or position sensor; the sensor tracks and reads the actual speed or position of the motor and feed it back to a controller to complete the servo system. The controller finds the difference between the desired and actual speed/position and drives the motor to the correct condition based on the control algorithm used. DC servo motor used in many

application i.e. satellite tracking antennas, remote controlled airplanes [7]. The control of the antenna system will be mainly position control and it depends on encoder or potentiometer read, as an actual position sensor, to find the deviation from the desired position. The encoder as a position sensor of a common use these days; many companies provide the DC motor attached directly to the encoder for the ease of use.

2.3 Position Encoders:

The position encoder is a device that converts the mechanical rotation of the motor shaft into electrical pulses, the number of generated pulses depends on the resolution of the encoder, which means the total number generated by the encoder per each shaft rotation. As the number of pulses increases the accuracy of the encoder will increase. Commonly the encoder is fixed to the rear side of the motor shaft; in case of motor without gear head the encoder output will directly give the position of the front side of the motor shaft but if the motor is connected to gear head, the front shaft position is given by multiplying the gear ratio by the encoder resolution.

Majorly we can classify the encoders into two types: incremental (Quadrature) and absolute position encoders.

2.3.1 Incremental and Absolute Position Encoders:

The incremental-also called quadrature- position encoder is the one that used in thesis work; it's commonly used with DC motors due to its simplicity when compared to the absolute one. It has two outputs in the form of a train of square pulses called channels; the channels have a phase difference of 90 degrees to indicate the direction of rotation based on which one is lead and which one is lag. The channel that leads during forward rotation will lag in the backward rotation. The main drawback of this type of encoder is that it doesn't give the absolute position of the motor shaft but it needs an external counter to find the angular position which is the problem that has been solved by the absolute encoder [22].



Figure 2.1: Incremental encoder output [22]

Another classification for the position encoders depends on the working mechanism which contains many types based on the encoder structure and the mechanism by which the pulses are generated i.e. optical encoder, Hall Effect encoder...etc., the one that used for this project is of Hall Effect type.

2.3.2 Hall Effect Position Encoder:

It depends on the Hall Effect element which is a conductive thin sheet with two output terminals. When subjected to magnetic field perpendicular to the electrical current flow direction it produces very small voltage signal [5]. The output signal is applied to an amplifying means i.e. operational amplifier, by using voltage reference that varies in magnitude and polarity, the output of the Hall Effect element would change its phase according to the reference voltage [18]. If the output is taken from two Hall Effect elements to be considered as two channels and a phase difference of 90 degrees in phase is produced between the two channels, this will give an encoder that can be used for position sensing.

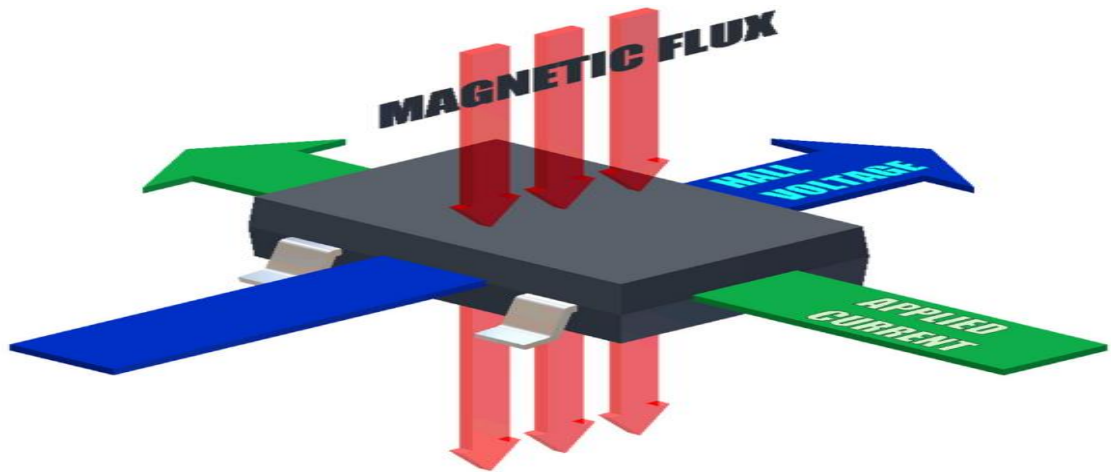


Figure 2.2: Mechanism of Hall Effect Element [5]

2.4 Arduino:

To establish a complete control system, a brain to monitor the control process is needed; in the case of the motor control, the control process is performed by calculating the difference between the actual and desired position, speed or torque and estimate the actuating signal based on the difference and the control method used. Different types of microcontrollers can be used to perform this task; one of them is the Arduino development board.

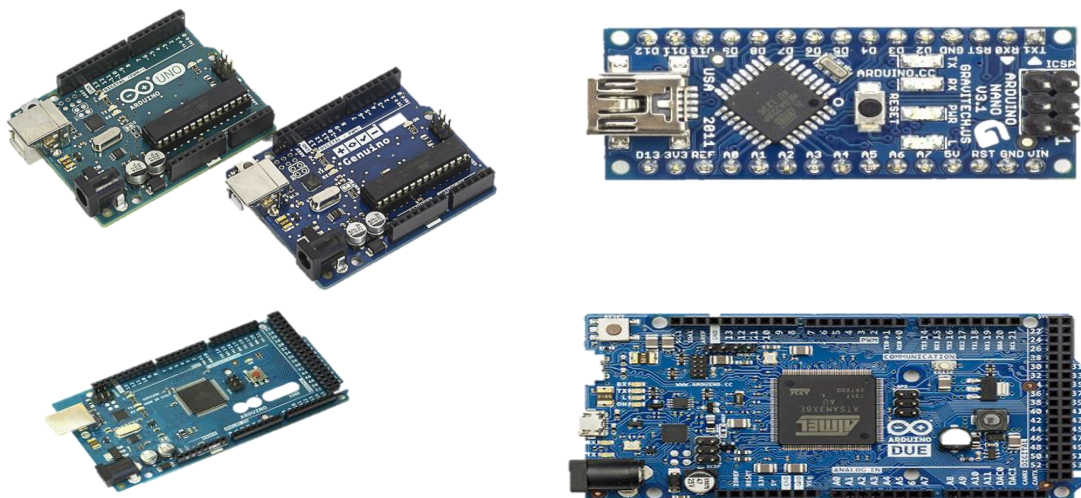


Figure 2.3: Some famous Arduino boards [11]

Arduino is an open-source electronics platform based on easy-to-use hardware and software [11]. It is a small microcontroller board with the ability to communicate with computers through USB plug which can work at same time as a power source; also Arduino can be supplied from an external source, for example, it can used 9V battery [14] or any DC power supply.

The beauty of the Arduino is that it is more than being a simple microcontroller; it is a complete development board that contains connection peripherals that make the project fabrication much easier and also make the Arduino board fitting different types of shields; the shields result in compact and easy to assemble projects. There are ready-made shields for many different purposes, i.e. Ethernet networks, LCD displays and touch screens, Motor control and many more shields [14].

Arduino can be programed in a number of ways [13] i.e. C language, Java, Matlab, Simulink, LabVIEW...etc., this gives it another advantage whereas it gives the user more options. One of the simplest and direct ways of programming is the graphical programming using Simulink, where full support is provided for the Arduino specially for the feedback-controller design[9]; so that the Arduino programming can be done without knowing a single word of a programming language [15], where it is a matter of dragging and dropping the Simulink blocks into the Simulink file to produce a complete system that runs in the Arduino board.

2.4.1 Arduino and Simulink:

Simulink is a block diagram environment for multi-domain simulation and Model-Based Design [12]. It has a special library for Arduino contains most of the basic blocks required for the programming purposes. Simulink has two releases of Arduino support packages, the final one (figure 2.5) – named: Simulink Support Package for Arduino Hardware- is a standard and installable package that comes with Matlab 2012b version [3] and above.

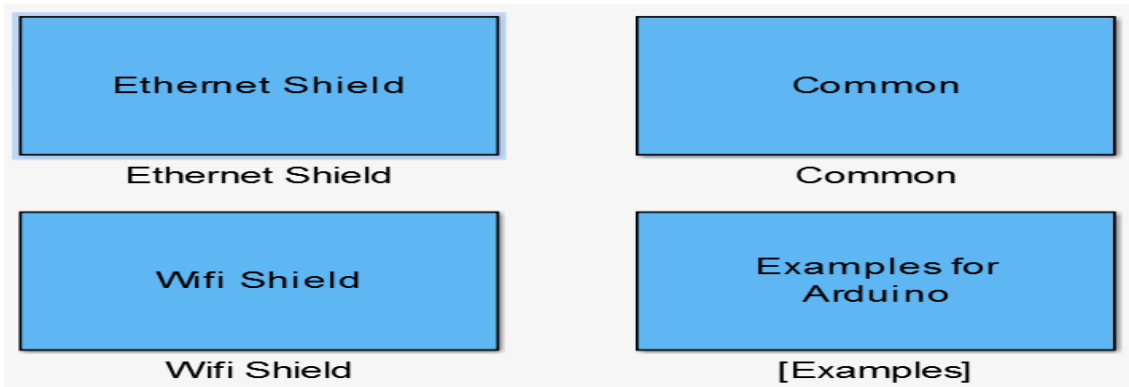


Figure 2.4: Simulink Support Package of Arduino Hardware

The old one (figure 2.6) - called Arduino IO Package - can be added to the Simulink library by running a particular (m file) named: install_arduino.

The new release of Arduino supporting package contains blocks that support some types of shields like Ethernet and Wi-Fi which gives the advantage of remote control either wire or wirelessly. All these are addition to the common blocks that contain the main Arduino pins interfaces.

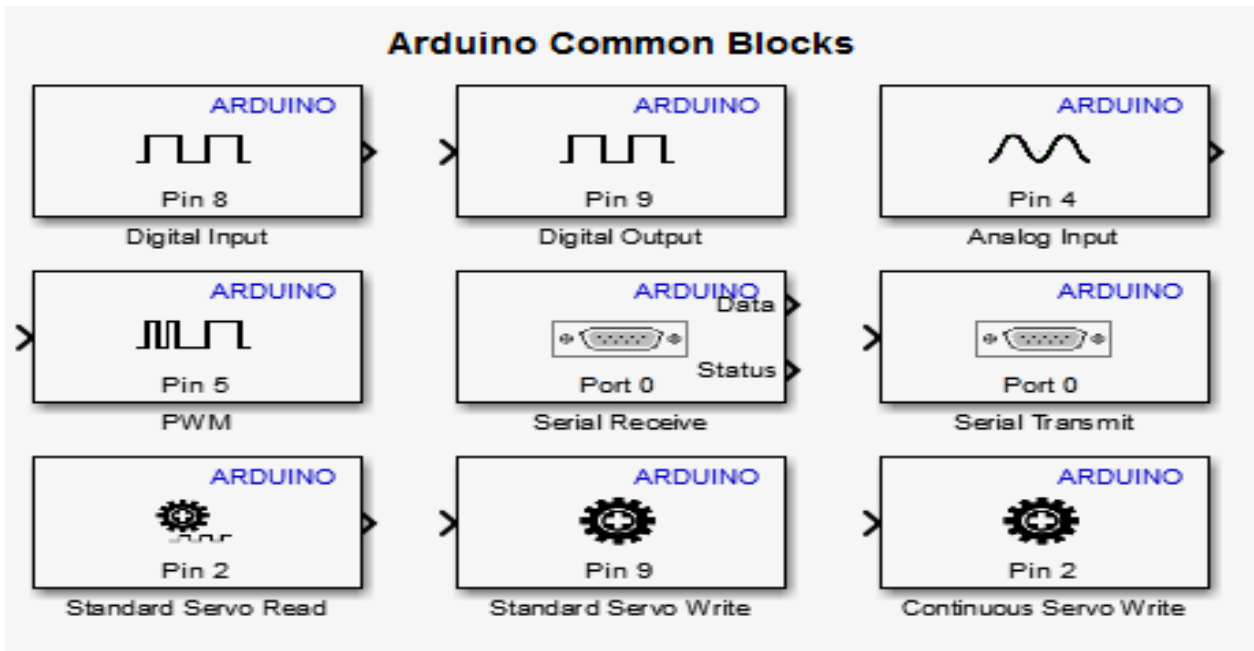


Figure 2.5: The common blocks in the Simulink Support Package for Arduino Hardware

The new release of supporting packages has some advantages over the older one. one of these advantages of the new release is that the Simulink model can be converted into a code by dumping it into the Arduino and it has the ability to run independently while the Arduino is disconnected from the host computer [3]. This facility doesn't available in the old release, whereas it works like the external mode by running a server program uploaded through IDE software. The Arduino exchanges the command with the host computer through a USB serial port.

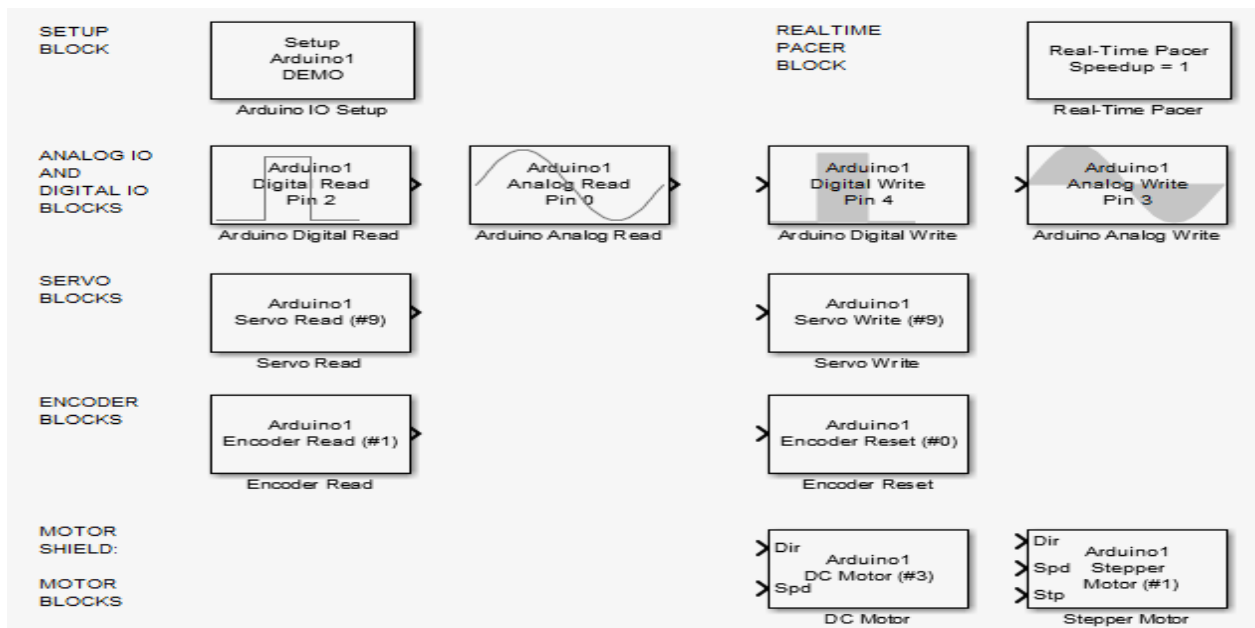


Figure 2.6: Arduino IO Package

The reason behind why the old release has been used for this project is that it has the ability to work in behaviour similar to the external mode in the new package with all types of Arduino; where the external mode is supported in the latest version for Arduino Mega and above. In this mode, the parameters of the Simulink model can be modified online while the system is running.

Another reason for choosing Arduino IO library is the availability of encoder block, which is very major in this project work, the thing that is not available in the new package.

2.5 Control Algorithms:

The control algorithm is the method that governs, describes and estimates the behaviour of the system when it works as a closed loop system by imposing the control operation on it based on the deviation from the desired system condition. The main task of the control algorithm is to minimize the deviation of the system from its desired condition by reading the actual status of the system and processing the difference between the two conditions.

There are many control methods ranging from classical to modern and from Single-Input and Single-Output (SISO) system to complex systems that have Multi-Inputs and Multi-Outputs (MIMO).

2.5.1 Proportional-Integral-Derivative (PID) Controller:

The Proportional-Integral-Derivative (PID) is a control algorithm that based on the difference (error signal (e)) between the desired set point and measured process value in a closed loop system [2]. The PID is one of the most commonly used types of controllers, more than half of the industrial controllers in use today are PID controllers or modified PID controllers[16]. The beauty of the PID controller lies in its compatibility with most control systems[16]. Also, it is one of the most used controllers in academic publication either alone or in comparative studies.

A standard PID controller is also known as the “three-term” controller [2]; it deals with both transient and steady-state responses. The transfer function of the PID is given by Equation 2-1:

$$G(s) = K_P + \frac{K_I}{s} + K_D \cdot s \quad 2.1$$

- The proportional term reduces the rise time and provides action proportional to the error signal.
- The integral term reduces the steady-state errors but it may slow down the transient response of the system.
- The derivative term improves the transient response [16] and reduces the system overshoot.

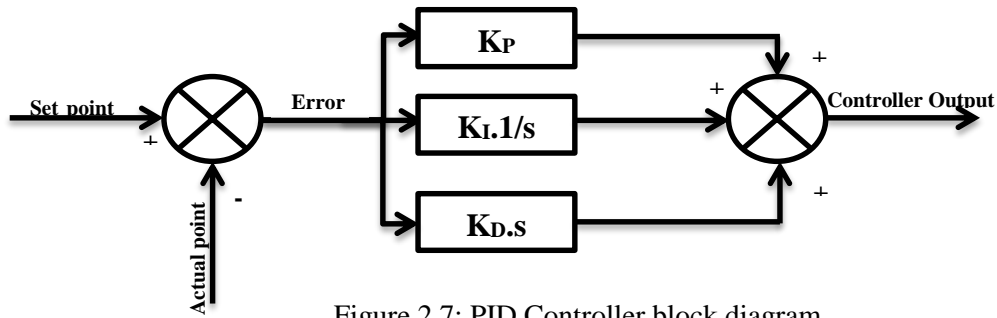


Figure 2.7: PID Controller block diagram

The process of choosing the best PID parameters' values to satisfy certain specification is called PID controller tuning [16]. There are many methods of tuning for the PID controller that can be grouped according to their nature and usage [2]; here is not a place to discuss them but one of the common ways of tuning is Simulink tool called PID tuning tool or PID tuner which is very effective for the people who are working in Simulink environment; the tool is applicable in the case of this project.

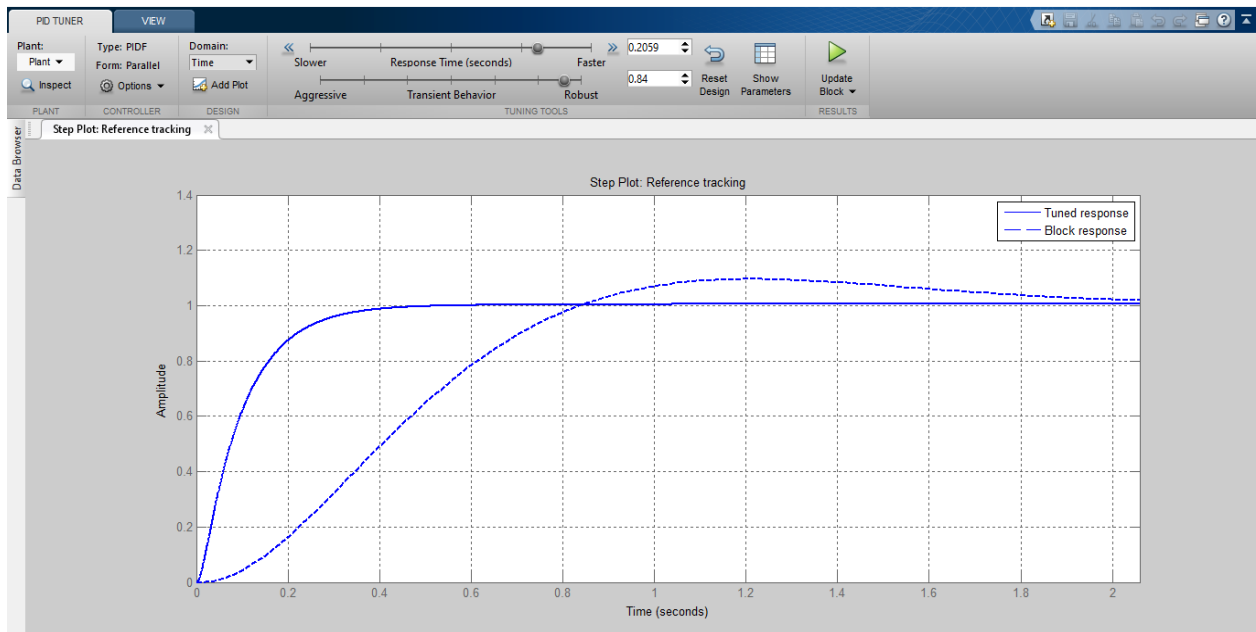


Figure 2.8: PID Tuning Tool

This tool is very useful if the system transfer function is available, it shows the current system response and it gives the ability to tune the PID controller to the desired response by watching online the change of the response curve by varying the response time between slow and fast, and the system behaviour between aggressive and robust. After setting the desired

response the tuned parameters (P, I, and D) will be displayed in their places in the PID controller block.

2.6 Summary of Some Case Studies:

In this section, a brief summary of some articles in the field of antenna control system is presented and discussed.

2.6.1 Satellite Tracking Control System Using Fuzzy PID Controller:

The study is a journal article authored by Van Hoi, Tran Truong, Nguyen Xuan Duong, and Bach Gia. This study is an automatic control system for an antenna with the ability to track the signal that comes from the satellite and position the elevation and azimuth angle based on the strength of the signal received from the satellite by translating it to an angle after the process of amplification and tuning. The signal processing is done inside the microcontroller which finds the difference between the desired and actual angles and does the correction based on the control and tracking algorithm used. The computer is used to provide the desired angle command and the satellite signal is used to find the deviation from the desired position. The control algorithms used are the traditional PID and fuzzy PID; the last one shows better performance compared to PID controller. The system is implemented and ran in real-time [24].

2.6.2 Design of Antenna Pointing System (APS)-its Control and Communication Challenges:

In a study published by S.Mohana Sundari, a design of antenna pointing system is discussed; a digital controller card programmed to control a two axis system to control azimuth and elevation angles using two motors and potentiometers to read the actual positions of both the azimuth and elevation angles after converting the potentiometers' read into digital signal so that it can be processed by the digital controller card. The digital controller card finds the difference between the desired angles - that collected from the GPS simulator and heading sensor for azimuth and elevation respectively - and the actual angles, and moves the system based on the error signal generated from the difference between the desired and actual positions. The error signal is the actuating signal that processed here using PI controller. The system is implemented in a real-time [23].

2.6.3 Antenna Position Control Systems, Review, and New Perception:

This paper [20] is a review of some papers and articles in the scope of the antenna control system; it gave summaries about what have been done in the field of antenna control system and it provided the methods of control used, brief about the components employed, and some about the future scope of this field. During the discussion, the author used to provide some results from the papers discussed along with some other drawings and figures for explanation purpose. The types of the controllers he has mentioned during the discussion are PI, LQG and H_∞ controllers The paper has covered around 5 journal articles within the field of antenna control system.

2.6.4 Antenna Control System using Step Tracking Algorithm with H_∞ Controller:

This is one of the good studies that done in the area of antenna control system; this study is published by Cho et al. [4]; it is a comparative study between PID and H_∞ controllers used to control the elevation and azimuth angles of a parabolic antenna using step tracking algorithm that tracks a certain satellite by scanning and finding the strongest signal and set the position antenna on that coordinates on which the strongest signal was captured. The H_∞ controller shows robust and less noisy responses when compared to PID controller. The system is implemented physically.

Chapter 3

System Concept, Design, and Implementation

This chapter gives an idea about the concept of the system, and the process of its design starting from the visualization until the real-time implementation. During the discussion, the specifications of the components used to implement the system are mentioned, along with pictures that show their locations inside the system.

3.1 System Concept:

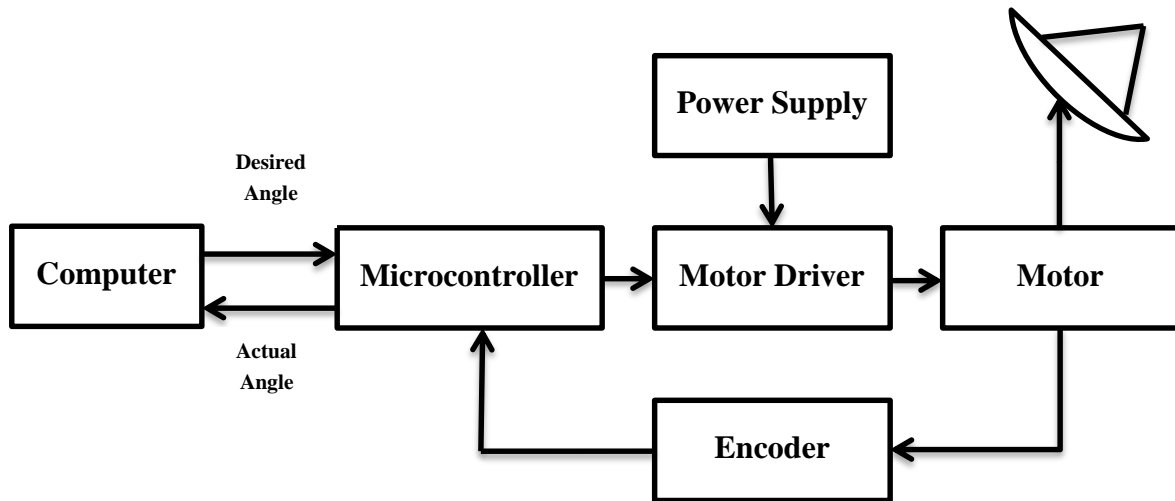


Figure 3.1: Antenna Control System

The system is a prototype control system for a parabolic antenna that controls its azimuth and elevation angles with a freedom of ± 45 and ± 180 degrees for the elevation and azimuth angles respectively. The movements of the azimuth and elevation are provided by two motors attached to gearheads to give the needed torque required to rotate the loads. The desired angle command is given through a host computer; the host computer passes the command to a microcontroller, which is an Arduino board in this case; the microcontroller distributes the command to the targeted motor according to a software configuration in the host computer that directs the command by activating certain pins in a motor driver shield attached to the Arduino board; the motor driver draws the needed current and voltage from an external supply to meet the load demand that couldn't be met by the Arduino directly. The software

used to run the system through the computer is a certain package in Simulink software that supports Arduino hardware. The command goes to the targeted motor and drives it to a certain position; this position is fed back to the Arduino through an encoder attached to the motor shaft; the Arduino finds the difference between the desired and fed back positions and treats the difference as an error signal. The system has to move forward or backward based on the error signal sign, which implies the application of control algorithm that guarantees the system stability and accuracy. The control algorithm and the tuning level will be displayed in terms of more matching between the desired and actual positions. The desired and actual positions display on the PC screen. The system is described in figure 3-1 above.

3.2 Design Visualization:

Before going to the hardware implementation it is necessary to visualize the design of the system to avoid any fatal error during the system real-time implementation. For this reason, the system framework has been designed using Solidworks; despite the design was ideal but it gave a very good visualization for the system with a little deviation from the real-time setup. In this section, the components visualized using Solidworks have been discussed step by step.

The design includes the base on which the azimuth rotation axis and all the system will be carried. The base is a box on the top of it the axis of the azimuth motor passes, while inside it the azimuth motor and the controller are placed.

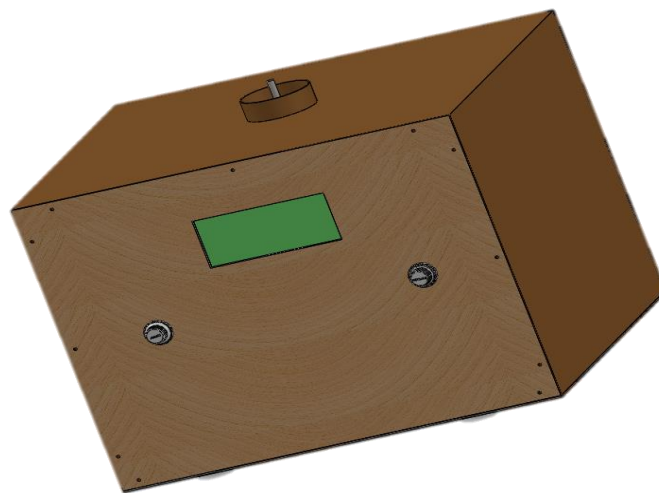


Figure 3.2: The base

The proposed base design contains – as shown in figure 3-2 - two keys (encoders or potentiometers) for the azimuth and elevation angles commands and a rectangular slot for LCD screen to display both the elevation and azimuth angles.

After the base and on the axis of azimuth motor comes azimuth rotator, which is another circular base that carries the elevation motor and the antenna with its arm. This base rotates with the azimuth motor and with it the antenna rotates within a range of ± 180 degrees.



Figure 3.3: Azimuth Rotator; a: Top view; b: bottom view

The proposed design of the azimuth rotator, as figure 3-3 shows, contains a place for bearing; the purpose of this bearing is to give smooth rotation and to carry the load so that the role of the motor will be only the rotation instead of carrying the load in addition to the rotation.

For the elevation movement, an elevation joint is designed. The elevation joint is fixed on azimuth rotator, which holds parabolic antenna on a hand that provides a rotation of ± 45 degrees (figure 3-4).

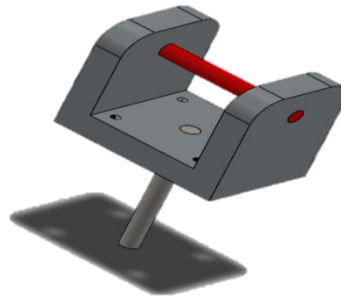


Figure 3.4: Elevation Joint

The antenna holder designed with small inclination on its top so that it provides some clearance between the base and the parabolic antenna attached to it. In the lower part of the holder passes the elevation axis (figure 3-5).

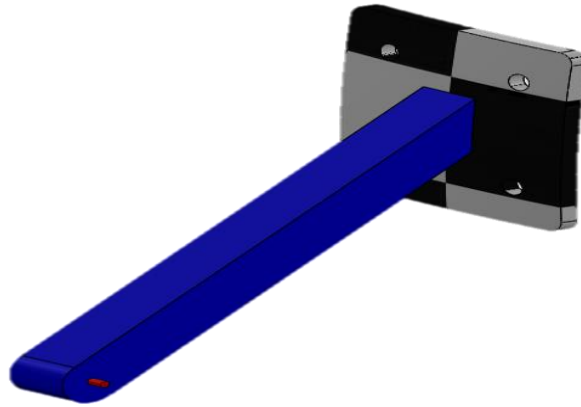


Figure 3.5: Antenna Holder

Figure 3-6 shows the complete assembly of the system frame without showing the motors and other components.

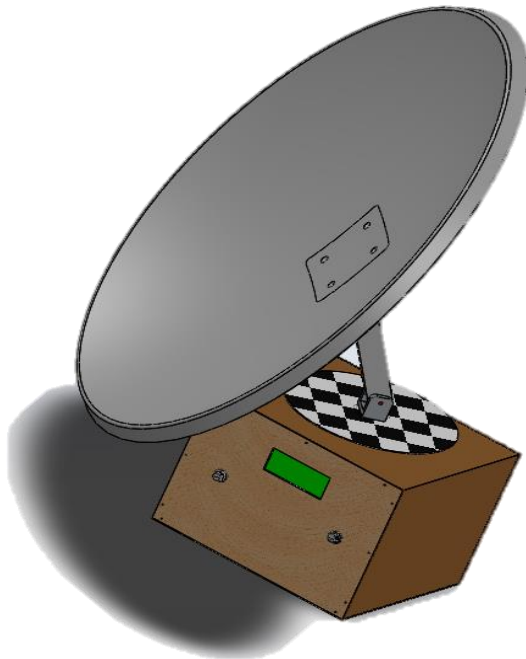


Figure 3.6: Antenna Control System visualization

3.3 System Implementation:

In this section, the real-time implementation of the antenna system is discussed in addition to the components used for the system operation.

3.3.1 System Components:

3.3.1.1 Pololu Motors:

The system uses two DC motors of Pololu brand for azimuth and elevation movements, the motors are attached with feedback encoders, the two motors are almost same except the gear ratios where it is 131:1 for elevation motor and 70:1 for the azimuth motor to give more speed since the azimuth covers more range of degrees than the elevation. The complete details of the motor are collected from the company's website as below.

Table 3.1: Azimuth and Elevation Motors Specifications [6]

Parameter	Azimuth	Elevation
Voltage (V)	12	12
Stall current (A)	5	5
Stall torque (oz-in)	200	250
Gear ratio	70:1	131:1
Gear length (mm)	24	26.5
Motor length (with encoder) (mm)	46.1	46.1
No-Load Speed	150	80

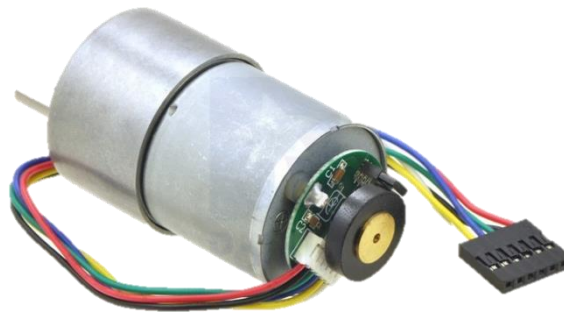


Figure 3.7: Pololu Motor with Encoder [6]

3.3.1.2 Hall Effect Encoder:

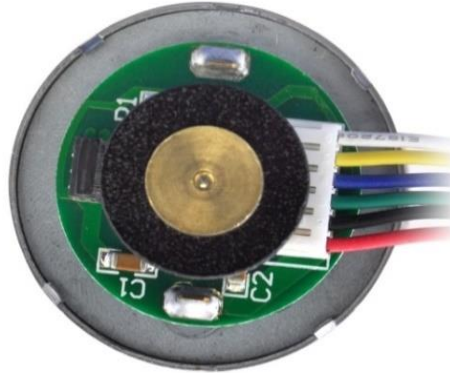


Figure 3.8: Hall Effect Encoder

As mentioned earlier and as figure 3-8 shows that the motor comes with an encoder to read the position of the motor. The encoder used with Pololu motor used in this project is a two-channel Hall Effect encoder used to sense the rotation of a magnetic disc placed on the rear portion shaft of the motor [6]. The encoder generates 64 counts per each revolution of the motor shaft for both channels and both high and low edges. These counts per motor shaft give high resolution when computed per revolution of the gearbox shaft whereas it is multiplied by the gear ratio [6]. The encoder – as figure 3-8 shows- has six leads coded as shown in the below table.

Table 3.2: Encoder terminals description [6]

Colour	Function
Red	motor power (connects to one motor terminal)
Black	motor power (connects to the other motor terminal)
Green	encoder GND
Blue	encoder Vcc (3.5 – 20 V)
Yellow	encoder A output
White	encoder B output



Figure 3.9: Encoder's A and B channels outputs captured through oscilloscope [6]

3.3.1.3 Arduino Mega 2560:

The microcontroller used in this project is Arduino Mega 2560. Mega 2560 contains ATmega2560 microcontroller along with many input/output pins for different functions which make the usage of it much easier and effective. The detailed specifications and description of The Mega 2560 are given in table 3-3 and figure 3-10 below.

Table 3.3: Arduino Mega 2560 specifications [11]

Property	Description
Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by boot loader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz
Length	101.52 mm
Width	53.3 mm
Weight	37 g

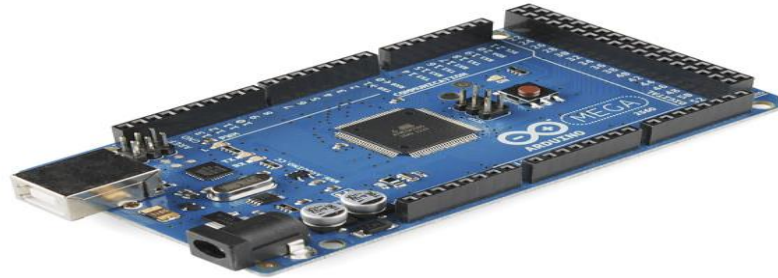


Figure 3.10: Arduino Mega 2560 [6]

The reason behind choosing Arduino Mega 2560 rather than choosing cheaper and smaller type of Arduino boards is that the Mega contains more interrupt pins than that we can find on smaller boards. The interrupt pins are needed here for the encoder channels.

3.3.1.4 Pololu dual MC33926 motor driver shield for Arduino:

Because of the limited Arduino output current we cannot supply the motor directly from it in most cases but we require an external supply; and if we have more than one motor we need a motor driver to impose control on them. Here a motor driver shield that can be attached directly to the Arduino is used to reduce the wiring required and to result in a compact design. Pololu dual MC33926 motor driver shield (figure 3-11) can be used with both Arduino Uno and Mega and has a good range of current that can run smoothly the both motors used in this project.



Figure 3.11: Pololu dual MC33926 motor driver shield for Arduino [6]

The motor driver shield has a specific pin mapping through which it connects the Arduino pins to the motor; figure 3-12 and table 3-4 explain it.

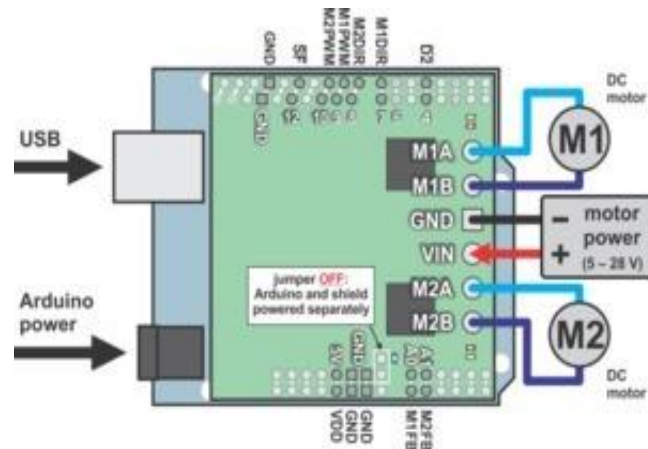


Figure 3.12: Motor driver shield pins configuration [6]

Table 3.4: Motor driver shield pin mapping [6]

Arduino Pin	Shield Pin Name	Basic Function
Digital 4	D2	Tri-state disables both outputs of both motor channels when LOW
Digital 7	M1DIR	Motor 1 direction input
Digital 8	M2DIR	Motor 2 direction input
Digital 9	M1PWM	Motor 1 speed input
Digital 10	M2PWM	Motor 2 speed input

To control the motors through Arduino using the motor driver the control truth table below should be followed.

Table 3.5: Simplified Motor Control Truth Table [6]

D2	MxPWM	MxDIR	Mode
HIGH	HIGH	LOW	Forward
HIGH	HIGH	HIGH	Reverse
HIGH	LOW	X	Brake
LOW	X	X	Coast

3.3.2 Wiring Setup:

The motor driver shield is attached to the Arduino as shown in figure 3-13; the encoder channels A and B of each motor are connected to the interrupt pins which are pins 2, 3,18,19,20 and 21 in Arduino Mega 2560. The motor power terminals are connected to MxA in the motor driver. The encoder ground is connected to the ground pin on the Arduino board while the encoder V_{CC} is connected to 5 V pin on the Arduino.

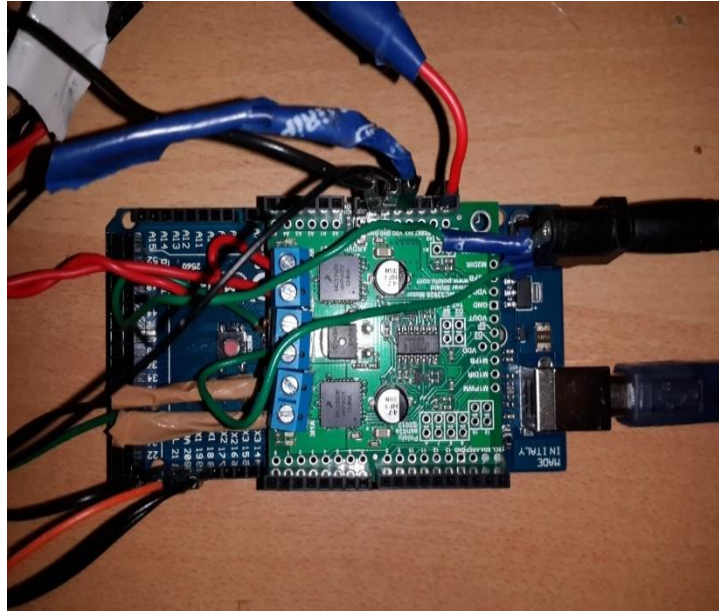


Figure 3.13: Electronics setup

3.3.3 Hardware Setup:

The hardware setup came according to the vision visualized from the CAD design but with small differences, where some details in the proposed design are eliminated from the real-time implementation because they found to be unnecessary. As mentioned earlier and shown in the figure 3-14 below; the base contains both the Arduino and azimuth motor. The azimuth motor shaft is connected directly to the azimuth rotator without bearings and this is one of the details of the CAD design that has been eliminated in the real-time design because of lack of necessity.

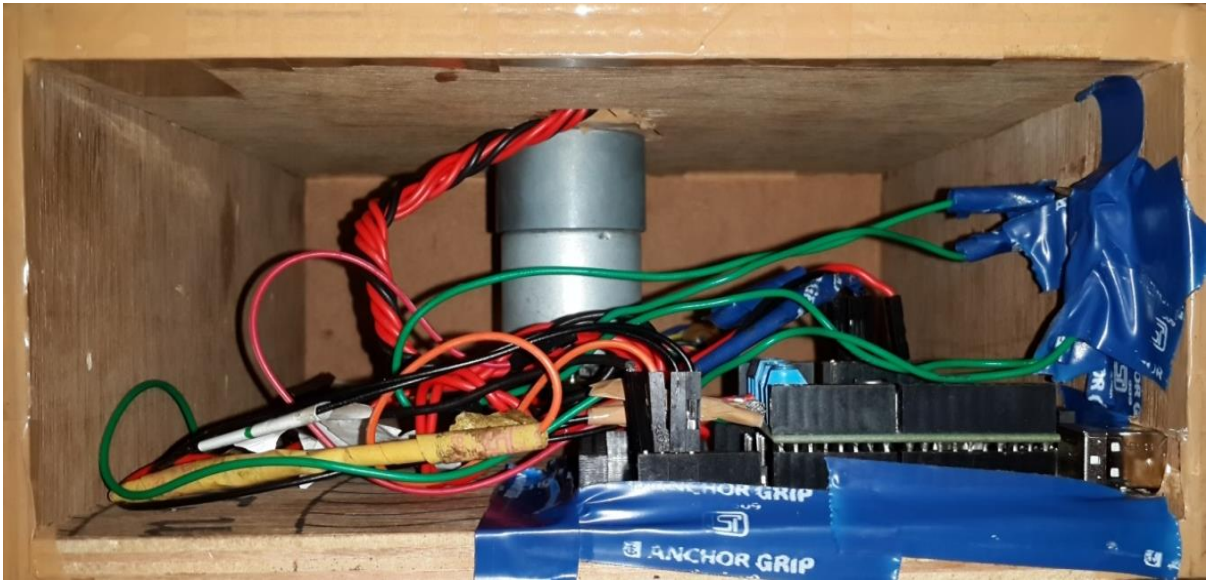


Figure 3.14: The base (internal look)

The elevation motor is placed on the azimuth rotator and its shaft directly connected to the antenna holder without any joint which is one of the details found in the simulated design while does not exist in the real-time.

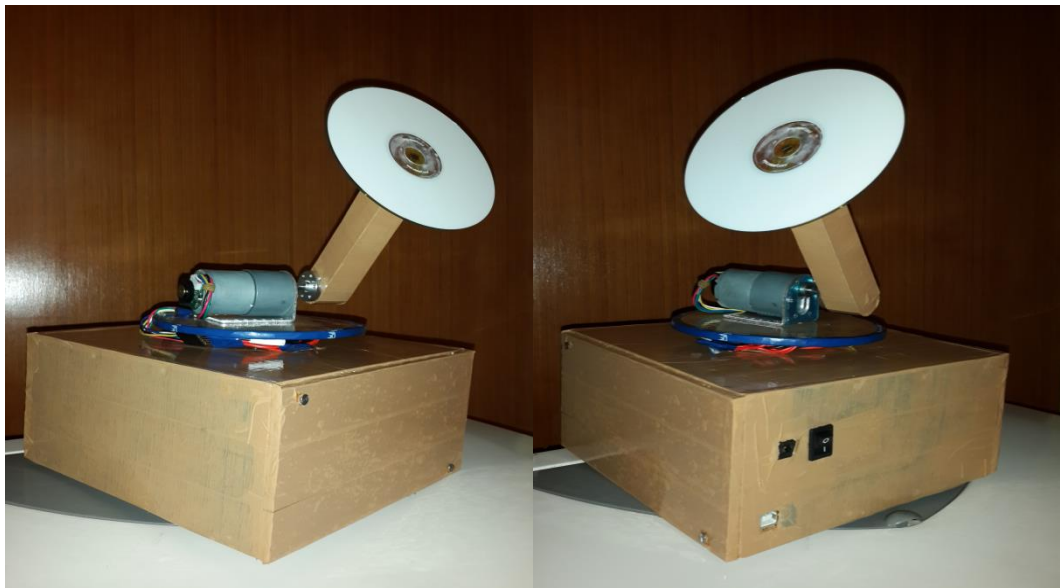


Figure 3.15: Antenna control system (different views)

Chapter 4

System Modelling and Controller Design

Antenna control system is a closed loop system that tries to respond to the command given in the form of the desired angle by getting the nearest response to the given command with a very small error. This process requires an application of control algorithm – The one chosen here is PID – that reduces the error to minimum possible value. The challenging issue in any control method is the estimation of its parameters; The PID controller has three parameters K_P , K_I and K_D ; there are many ways to estimate these parameters one of them is a tool in Simulink called PID tuning tool; this tool requires the transfer function of the system for which the PID parameters is required. Since the antenna control system implemented here is completely hardware system, this requires a specific process to estimate its transfer function and then based on it the estimation of the PID parameters will be done. This chapter discusses the method of the transfer function estimation, the PID controller design using this transfer function and the system configuration in Simulink after the PID parameters estimation.

4.1 System Transfer Function:

The transfer function of both the azimuth and elevation of the antenna control system must be estimated independently from each other because each part has its own parameters and specifications that are totally different from the other.

The process of the transfer function estimation starts with data acquisition, then estimation of the transfer function from the data acquired and finally the validation of the transfer function by different data to see its level of fitness. The process can be summarized in figure 4-1 below.

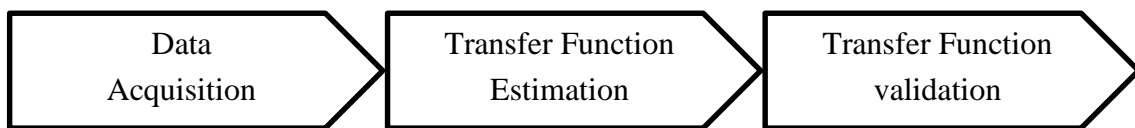


Figure 4.1: Transfer function estimation process

4.1.1 Data Acquisition:

We go for the data acquisition to estimate the transfer function of a system when there are no sufficient data provided from the manufacturer or the system design is modified such that the provided data won't be sufficient to fulfil the transfer function calculation requirements. The idea of the data acquisition based on running the system in open loop setup (figure4-2) and logging the input and output signals using the signal logging feature (figure4-3) in Simulink [25] which creates a data object in the Matlab workspace contains all the logged input and output signal as a time series objects [25].

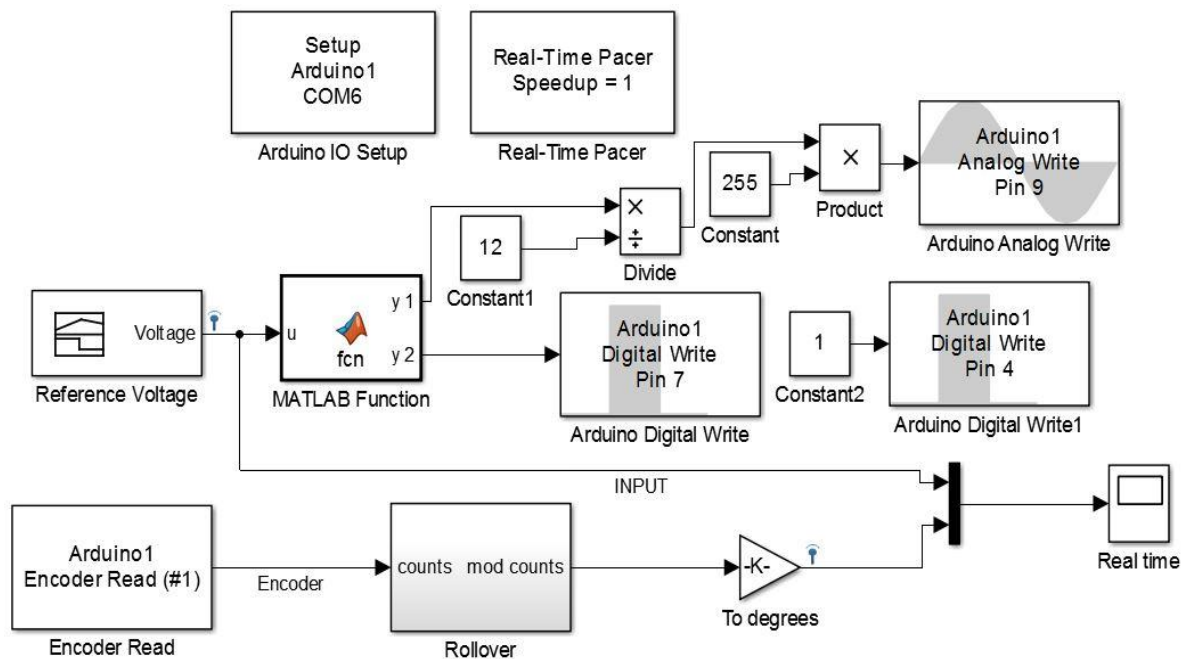


Figure 4.2: Open loop Simulink setup

The model shown in figure 4-2 is almost same for both the azimuth and elevation; the only difference is the Arduino pins activated in each case.

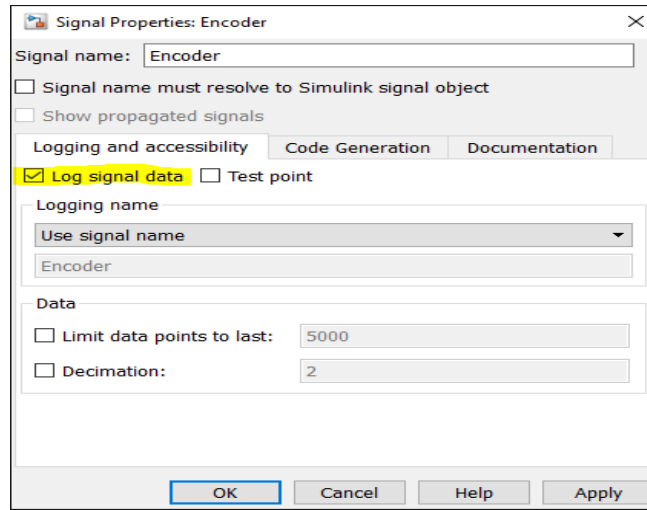


Figure 4.3: Signal data logging

For the purpose of the transfer function estimation and validation four data sets have been logged for both the azimuth and elevation transfer functions (two data sets for each) as shown in figure 4-4.

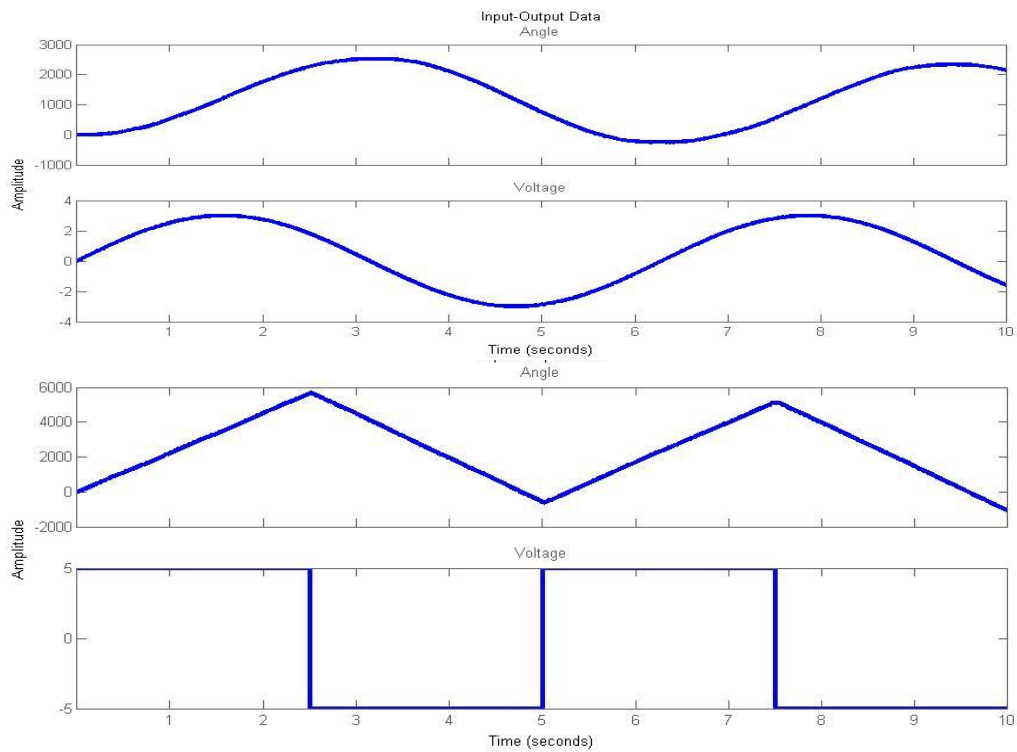


Figure 4.4: Data sets for elevation

The data sets for azimuth and elevation are almost same in the dynamic with little differences in the angle amplitude due loads and motors' torques dissimilarities.

4.1.2 Transfer Function Estimation:

After the input and output signals have been logged and saved as data objects the estimation of the transfer function is now becoming the next step. The transfer function is estimated using System Identification Tool (figure 4-5) via importing the two data sets for each system separately. By using one of them as working data and selecting the option of transfer function estimation from the pull-down menu, the estimation process can be started.

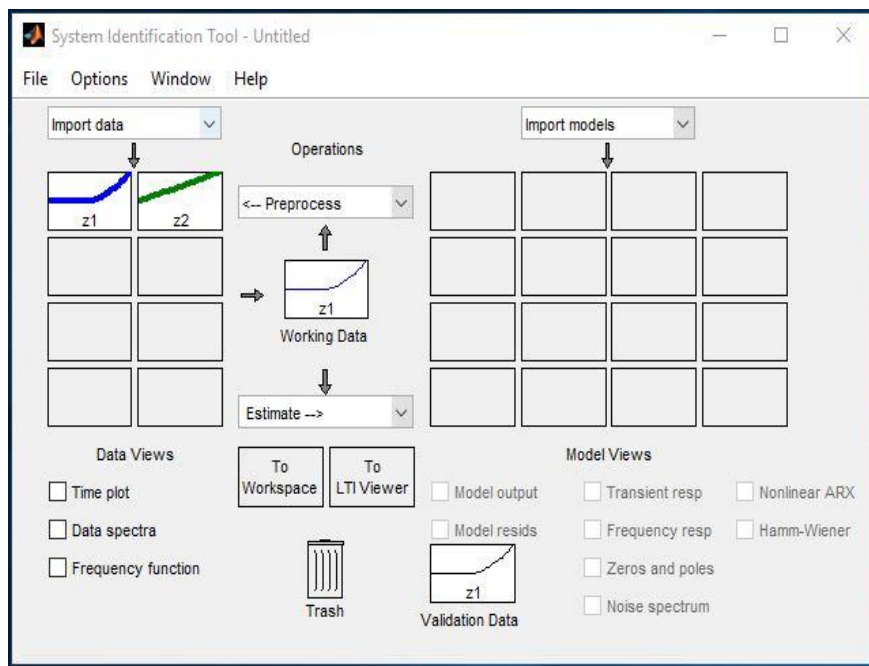


Figure 4.5: System Identification Tool with two data sets imported

By setting the number of poles and zeros and starting the estimation process the transfer function of a linear system is obtained along with its fit to the data used for the estimation process (figure 4-6).

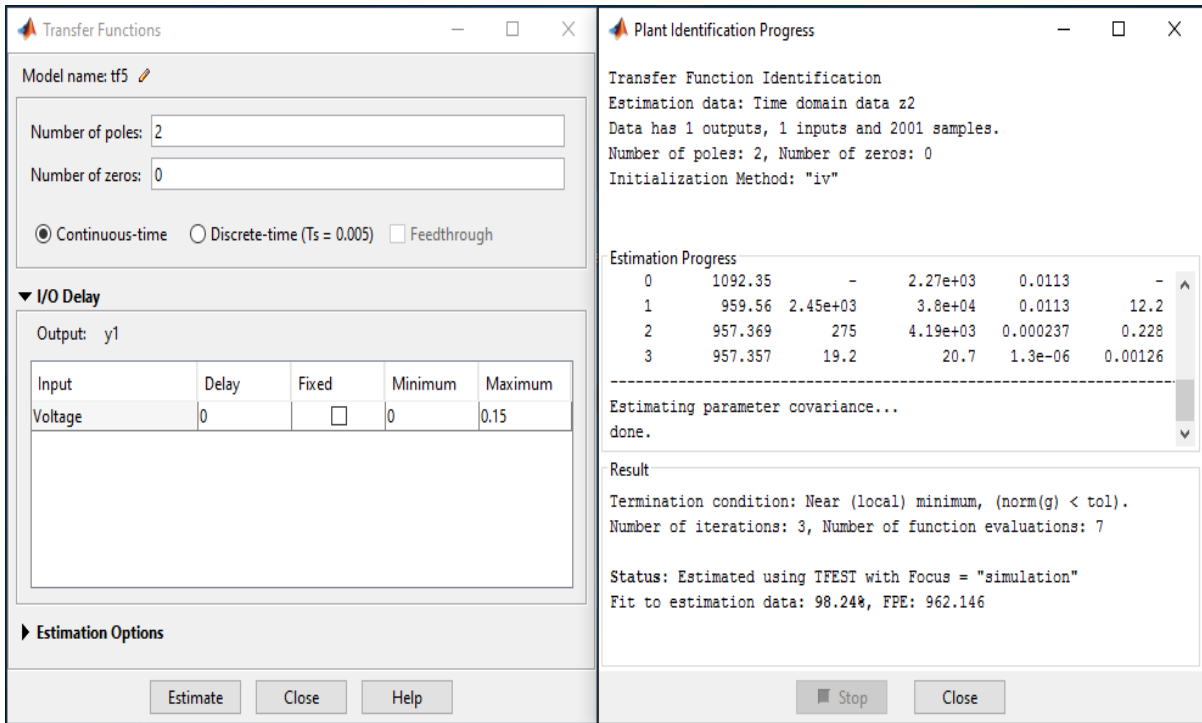


Figure 4.6: Transfer Function estimation GUI

The estimated transfer functions for the azimuth and elevation are given below by Equation 4-1 and Equation 4-2 respectively.

$$\frac{4574s^2 + 7937s + 4999}{s^3 + 1.623s^2 + 1.111s + 59e^{-10}} \quad 4.1$$

$$\frac{2.177e^4}{s^2 + 45.32s + 2.019} \quad 4.2$$

The estimated linear system transfer functions for both the azimuth and elevation can be plotted– for the purpose of comparison– against the estimation data to watch their fitness in the form of graphical representation (figure 4-7).

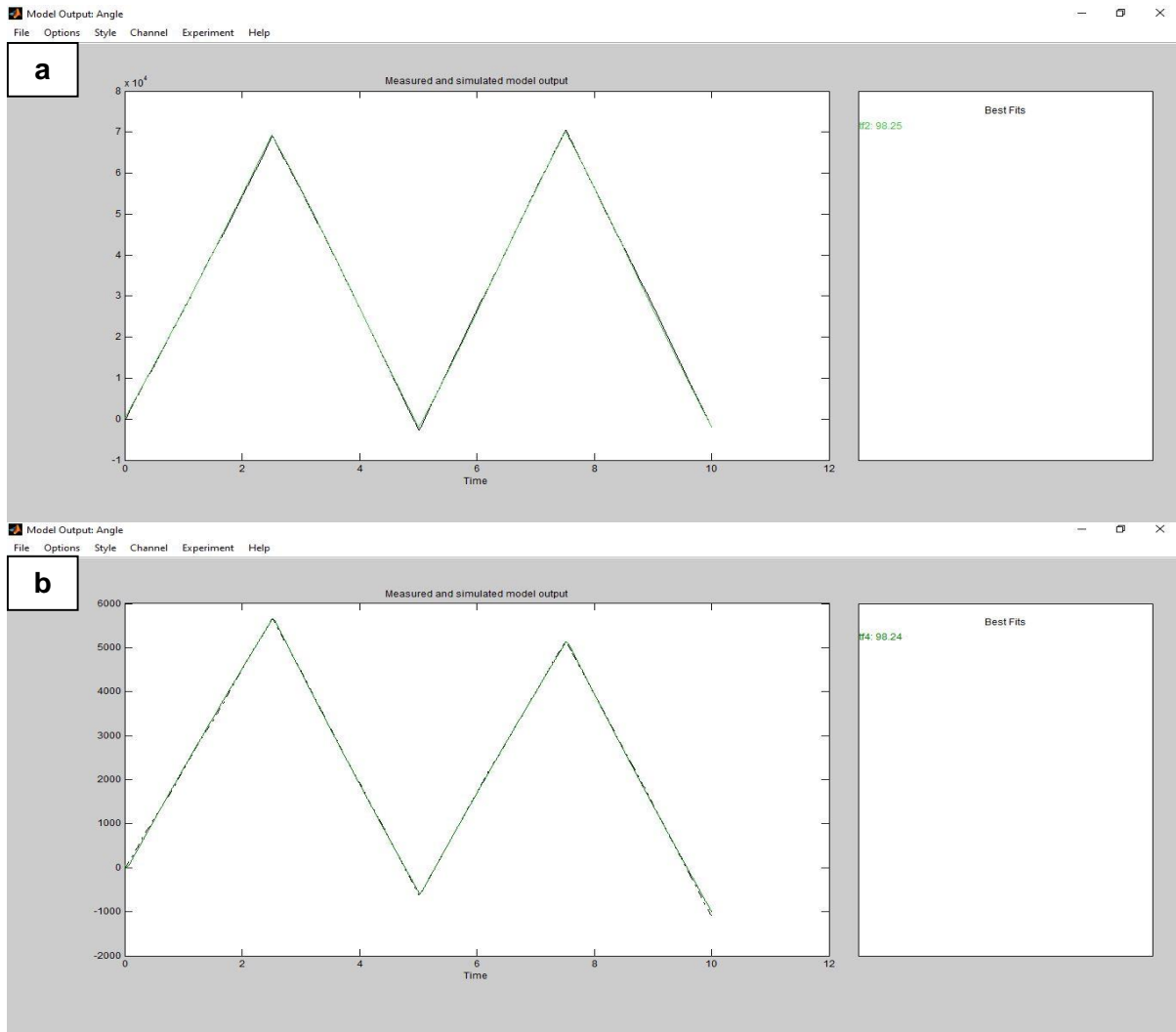


Figure 4.7: Comparison between the estimated models and estimation data for a: azimuth, b: elevation

As figure 4-7 (a and b) above shows, the fitness between the estimated system models and the estimation data is 98.25% and 98.24% for the azimuth and elevation respectively, which are very good percentages of fitness to a level that the graphs of the system models and the estimation data are almost identical.

4.1.3 Transfer Function Validation:

To verify that the transfer functions estimated represent the system dynamics, they should be validated against an independent data sets [25] (figure 4-8). As more as the data fits the system model as much as the model represents the system dynamics.

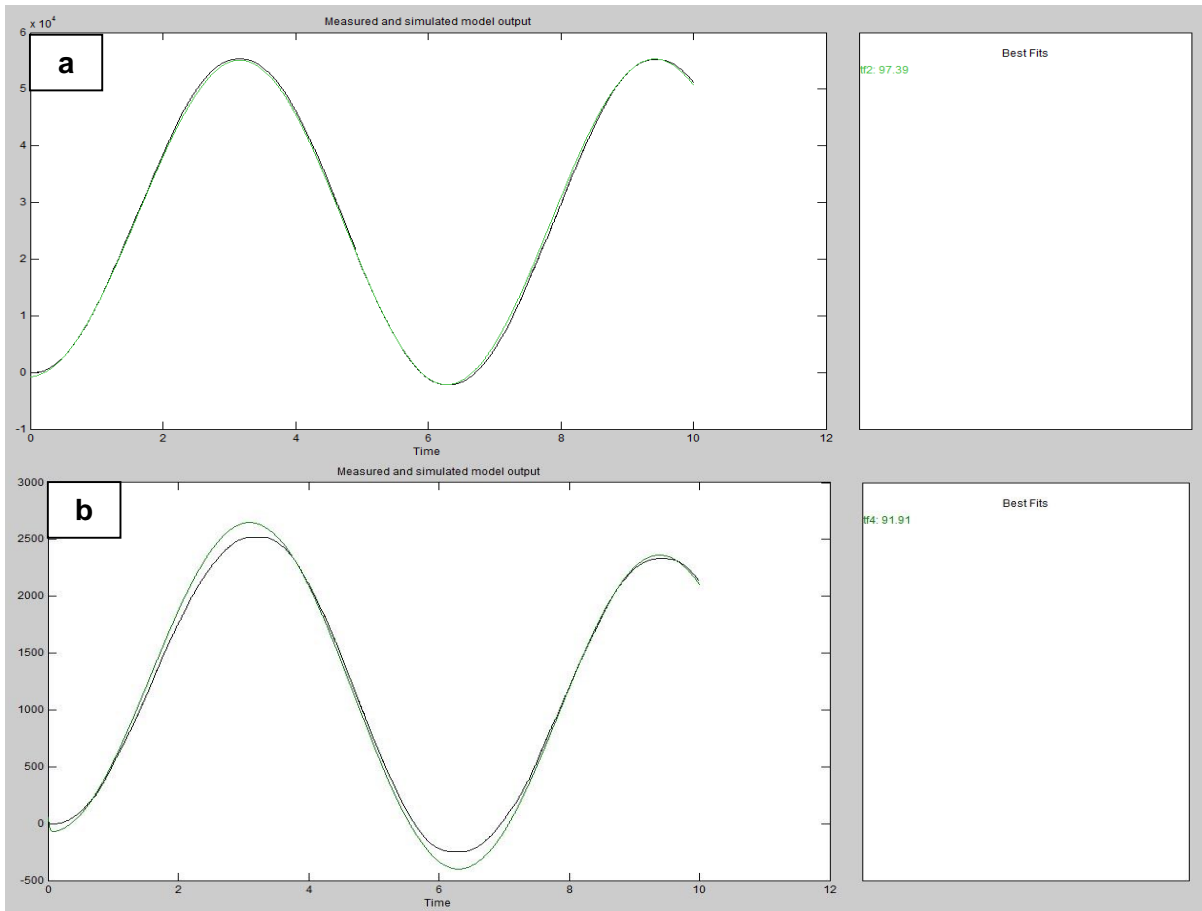


Figure 4.8: Comparison between the system responses and validation data a: azimuth, b: elevation

Figure 4-8 (a and b) displays 97.39% and 91.91% as the levels of fitness between the system model and validation data for azimuth and elevation respectively; they are considerable percentages which ensure that the estimated transfer functions represent the system dynamic perfectly.

4.2 PID Controller Design:

By using the estimated transfer functions of the system, the design of the PID controller parameters can be done in simulation environment which would be easier and safer than doing it directly in the real-time system. The PID controller parameters are found after simulating the system by placing the transfer functions in a Simulink model that includes PID block with PID tuning Tool (figure 4-9). The tuning process that has been done using the

tuning tool – figure 2.8 - gave the best response for the system and accordingly the PID parameters are collected.

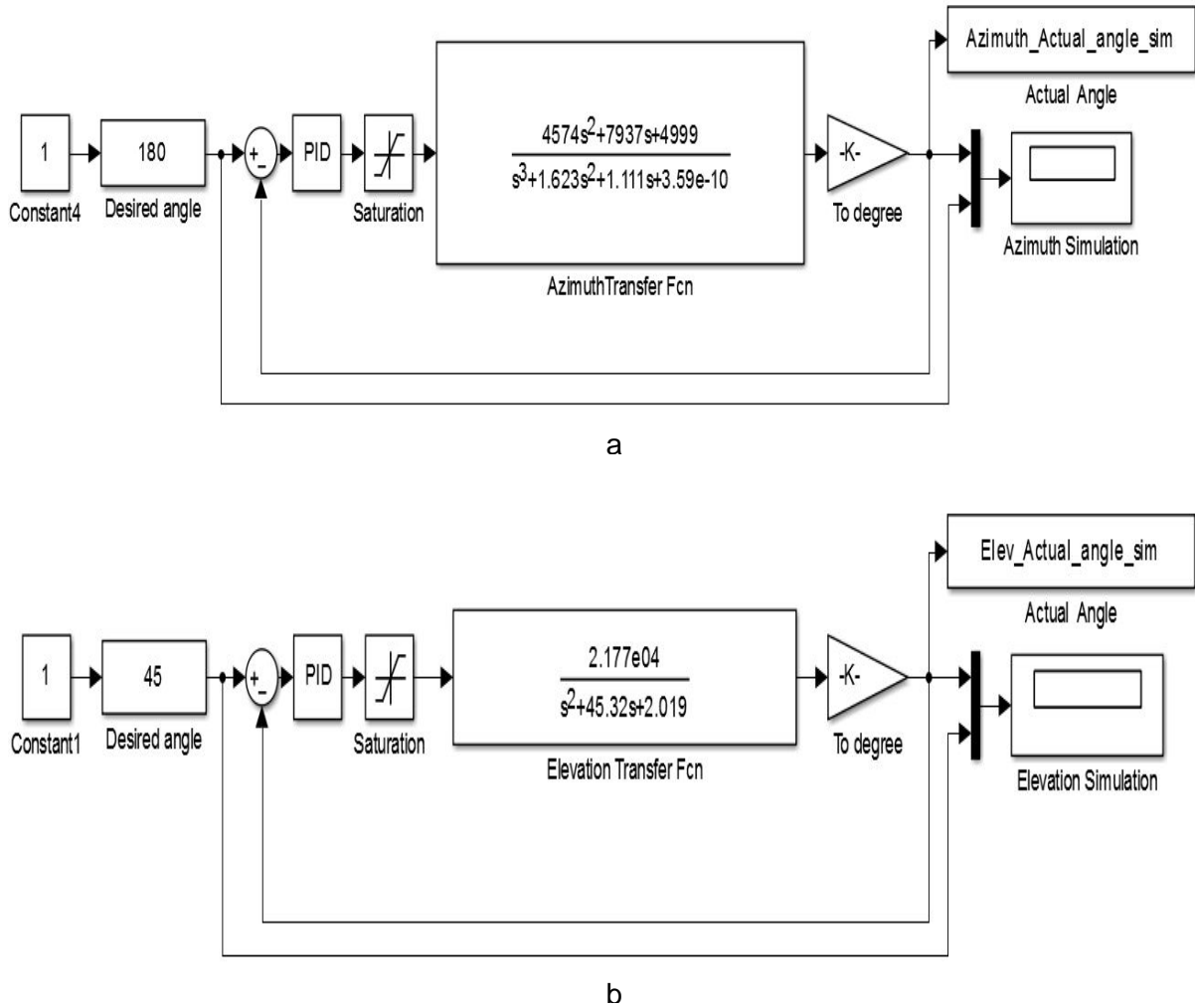


Figure 4.9: Simulink simulation models for a: azimuth, b: elevation

The estimated PID parameters have been used to run the system in the real-time after establishing a closed loop real-time Simulink model (figure 4-10) using Arduino IO Package (figure 2-6). Since the real-time system mostly has some nonlinearity and the parameters estimated are for a linear system so that the PID parameters estimated in the simulation environment can be a good initial estimation for the required parameters but they need a small effort of tuning to get the perfect real-time system response.

The real-time Simulink models are almost of the same setup for both the azimuth and elevation subsystems, the only differences that they have are the pins of the Arduino need to be activated to pass the power to the meant motor, and the numbers by which the outputs of the encoders should be divided to convert the encoder counts to degrees; these numbers depend on the gear ratios of the motors; which are found to be 12.4444444 and 23.28888889 for azimuth and elevation motors respectively.

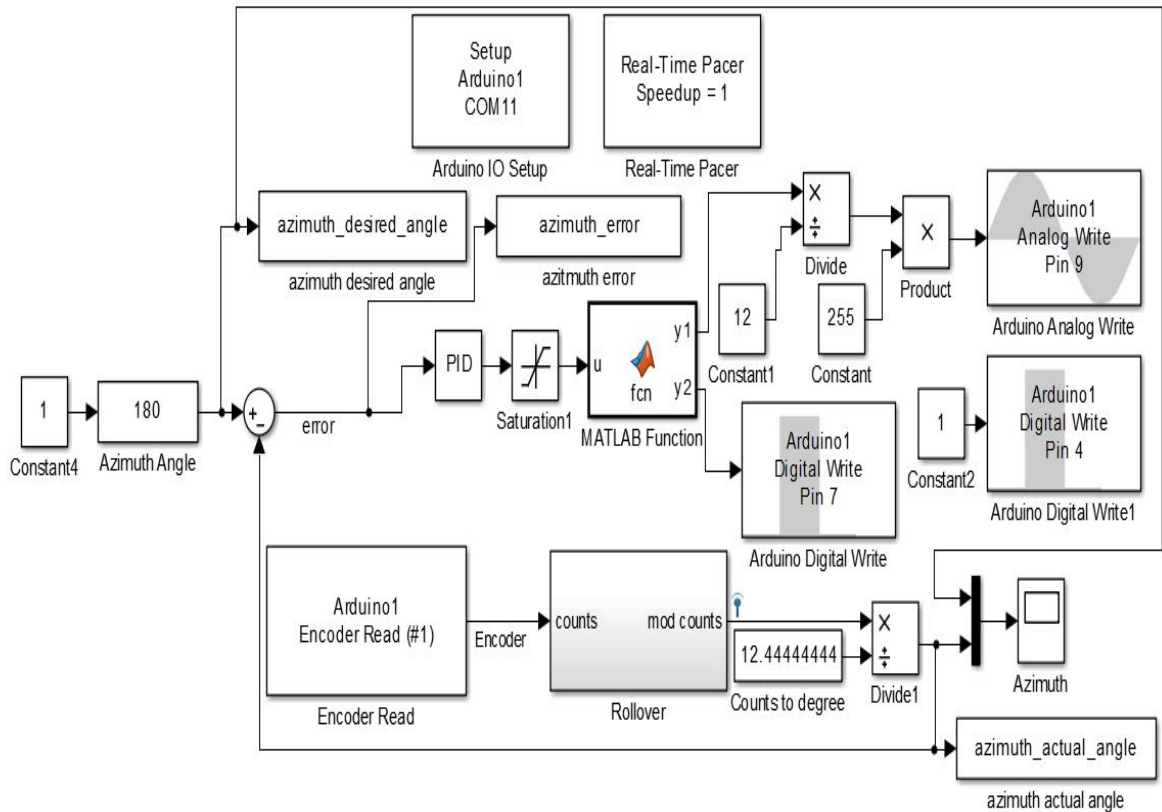


Figure 4.10: Simulink model of the azimuth real-time subsystem

Both the subsystems can be assembled in one system that can run the azimuth and elevation from one Simulink model

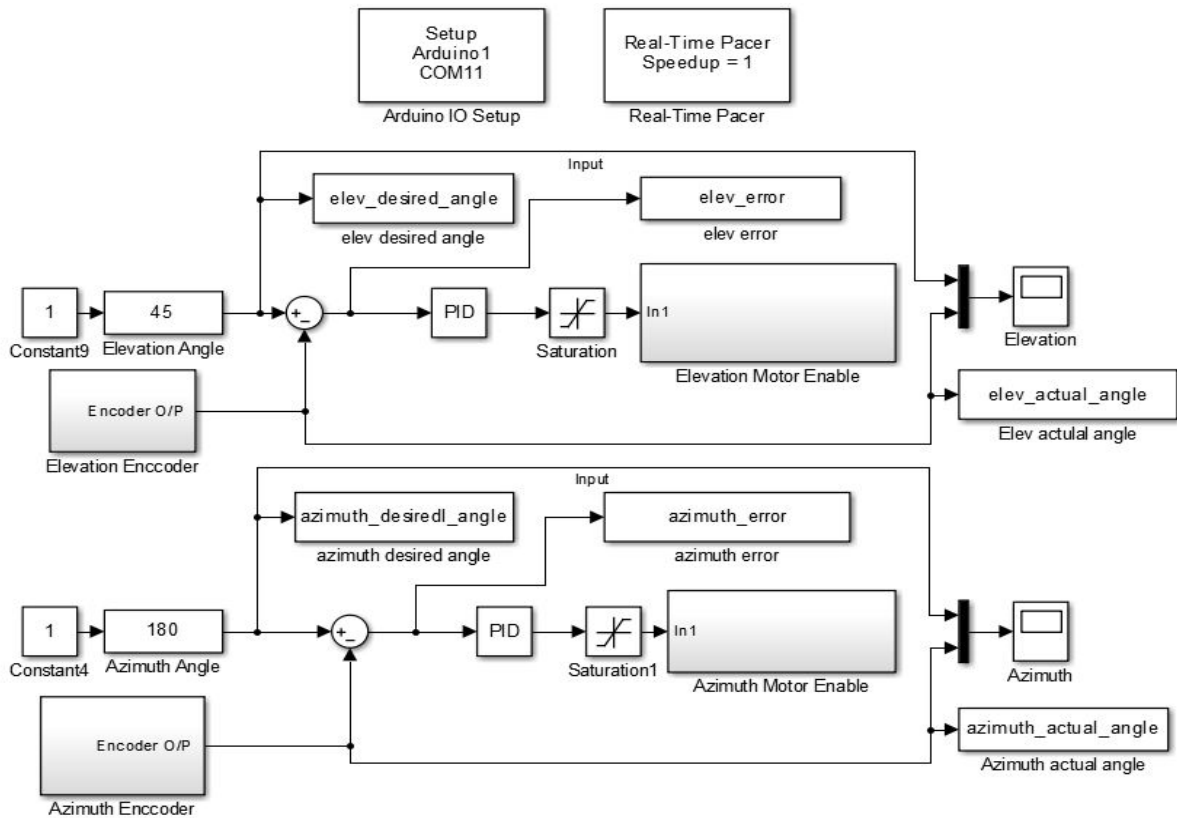


Figure 4.11: The Simulink model of the whole system

The parameters of the PID controller for both the azimuth and elevation subsystems after the process of refining are shown in table 3-1 below.

Table 4.1: PID controller parameters for azimuth and elevation

Parameter	Azimuth	Elevation
K_P	0.2	0.36
K_I	0.2	0.0052
K_D	0.002	0.0027

Chapter 5

Results and Discussions

The antenna control system is mainly made to carry the antenna to its desired azimuth or elevation angle as well as to resist any disturbances caused by any external reasons that tend to move the antenna from its desired position. The results in this chapter are collected based on the system objectives; so some results are to test the traceability of the system to a certain signal (i.e. rectangular, step) and some results are collected as responses of the system when given a certain desired angles to watch how close the output would be to the given commands; and finally the system is tested against random disturbances to observe its ability to absorb and eliminate the disturbances by carrying back the system to its given desired position.

Since the system is simulated initially for the purpose of finding the best PID controller parameters so that the result are displayed here as a comparison between the simulation, actual and desired responses. Also, the results are discussed and shown for both the azimuth and elevation subsystems.

5.1 The Simulation Results:

The results of the simulated system are collected and plotted against the desired responses to show the similarity between the ideal and simulated responses of the azimuth and elevation subsystems.

To test the ability of the system to trace a certain signal by generating an output looks similar to the signal shape given to the system, both the azimuth and elevation subsystems are given rectangular functions and the outputs are plotted as shown in figure 5-1 below. The rectangular signal is mainly given to view the behaviour of the system when the system suddenly changes from high to low signal suddenly or in other when the system suddenly changes the direction of rotation of the motors driving the loads. As figure 5-1 shows that the simulated system suffers from some disturbances at the corners of the rectangular function before it settles down and shows a very nice match to the desired responses.

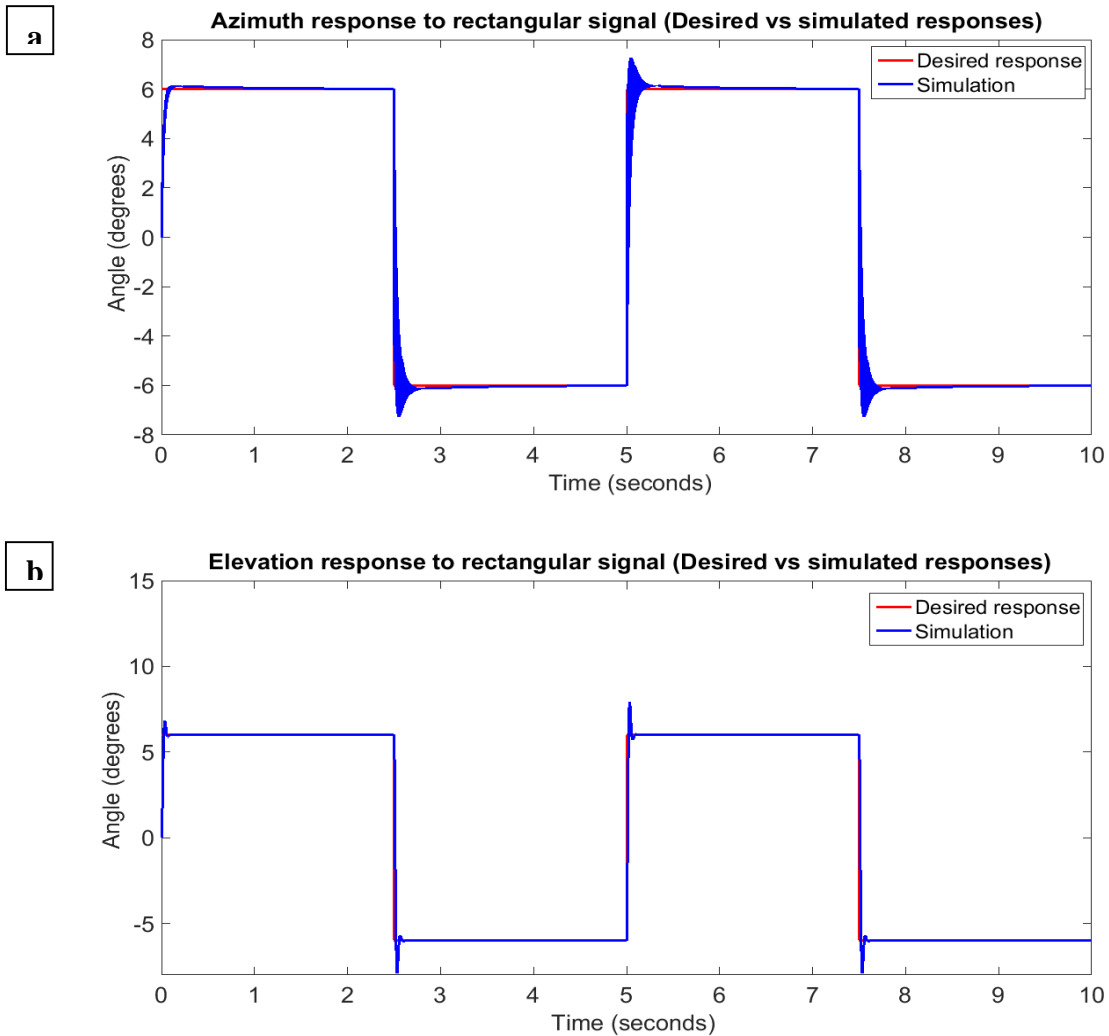


Figure 5.1: Response of the system to rectangular signal, a: azimuth, b: elevation

To find out the system behaviour and characteristics when tested against step function; the system has been run for 20 and -30 degrees azimuth and elevation angles. The purpose of running the system for positive and negative angles is that the system– as mentioned earlier– covers its proposed ranges of azimuth and elevation angles by dividing it into two ranges that can be covered by running the system clockwise and counter clockwise. So that the 360 degrees of the azimuth range and the 90 degrees of the elevation range can be covered by dividing the range into ± 180 and ± 90 degrees for the azimuth and elevation respectively. This produces a shorter journey to the system needed to be travelled when commanded to a certain position. Figure 5-2 below shows the responses of the system to the step commands given in terms of 20 and -30 degrees angles.

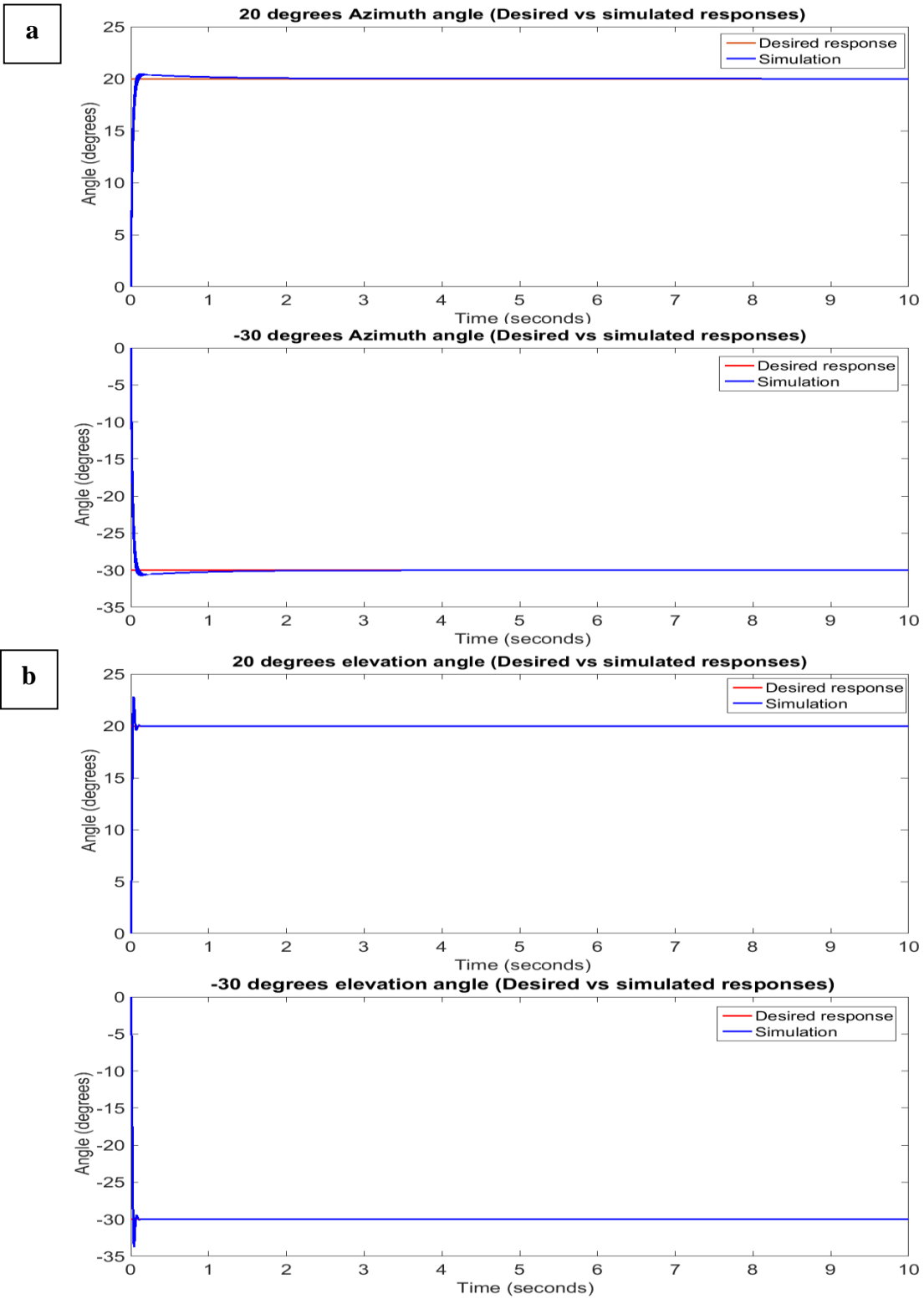


Figure 5.2: System responses to 20 and -30 degrees angles, a: azimuth, b: elevation

5.2 Real-time Results:

After the system behaviour has been guessed by running a simulation version of it; this made the expectation of the safety margin truthful. The PID controller parameters used to run the simulation can be used for the real-time operation. All the cases used for real-time are those WHO have been used to run the simulation version, in addition to some other cases which is applicable in the real-time only.

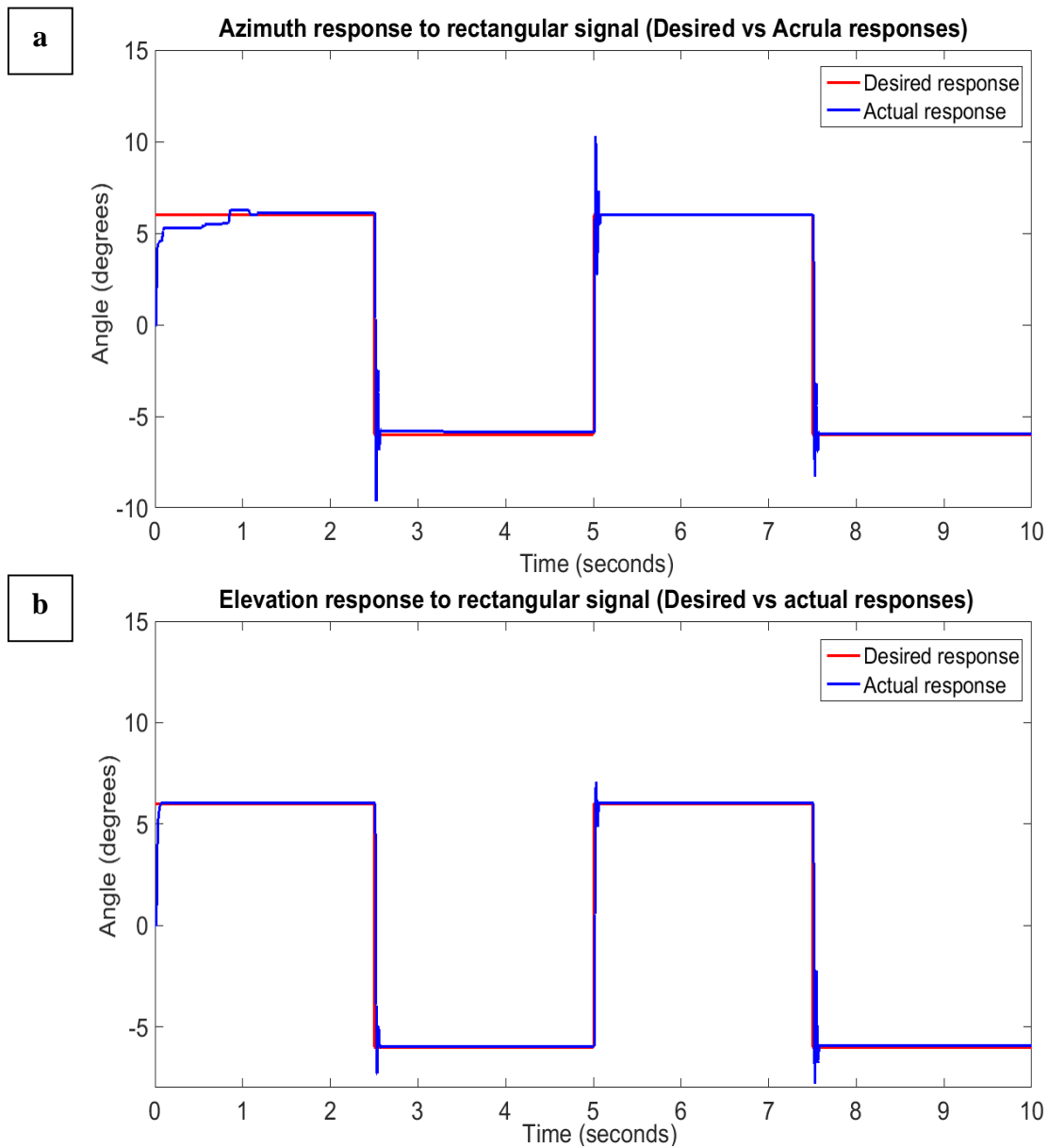


Figure 5.3: real-time responses for rectangular signal, a: azimuth, b: elevation

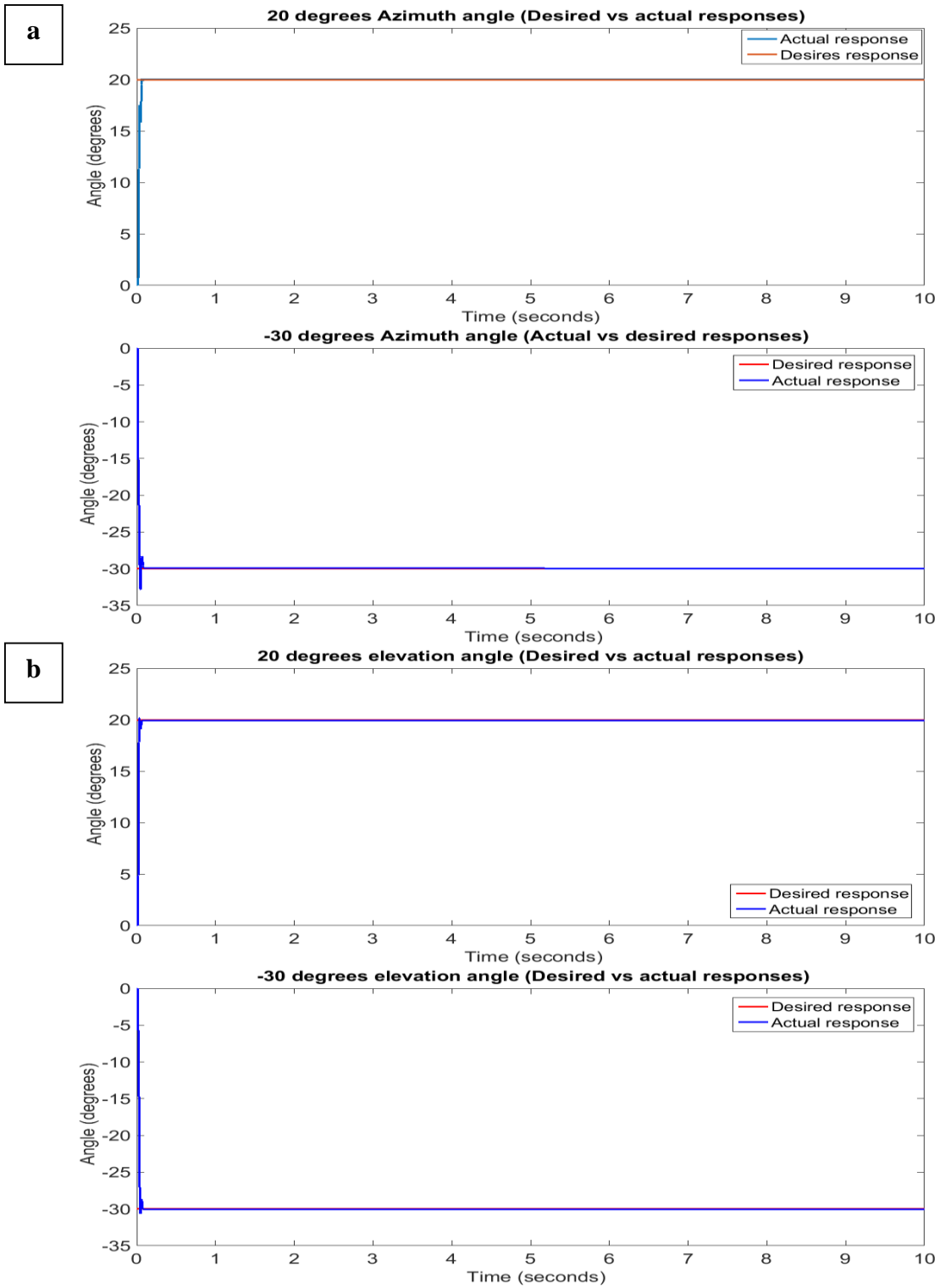


Figure 5.4: Real-time system responses to 20 and -30 degrees angles, a: azimuth, b: elevation

Figures 5-3 and 5-4 show the responses of the system for rectangular and step functions and its responses in all the cases seems to be very good when compared to the desired responses.

The real-time system is also run for different angles to watch its accuracy when travelling from command to another (figure 5-5); as well as it has been run for 20 degrees angle while subjected to disturbances to see how it resists and absorbs the disturbance by carrying back the system to the desired set point (figure 5-6).

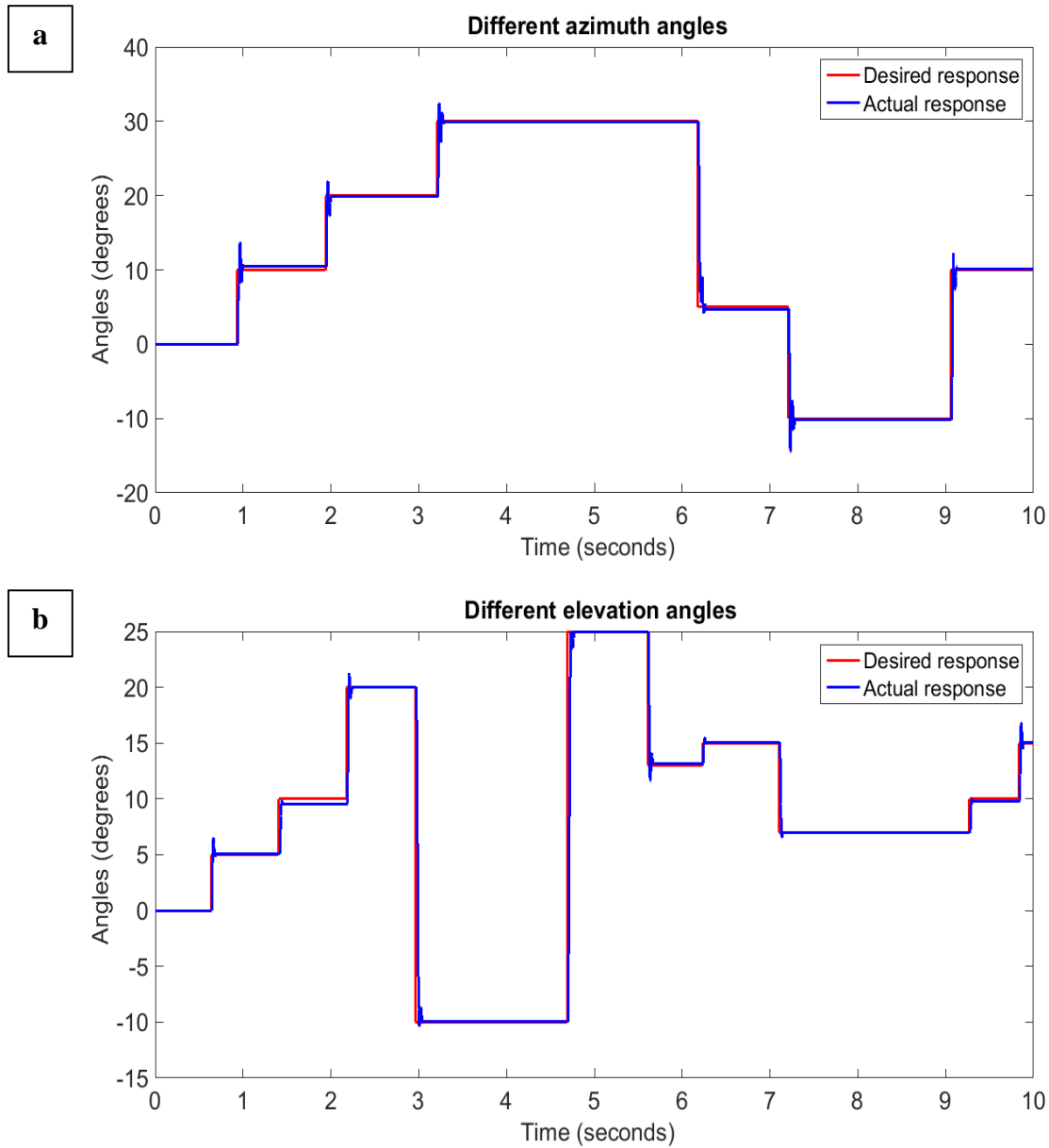


Figure 5.5: The response of the system to different angles, a: azimuth, b: elevation

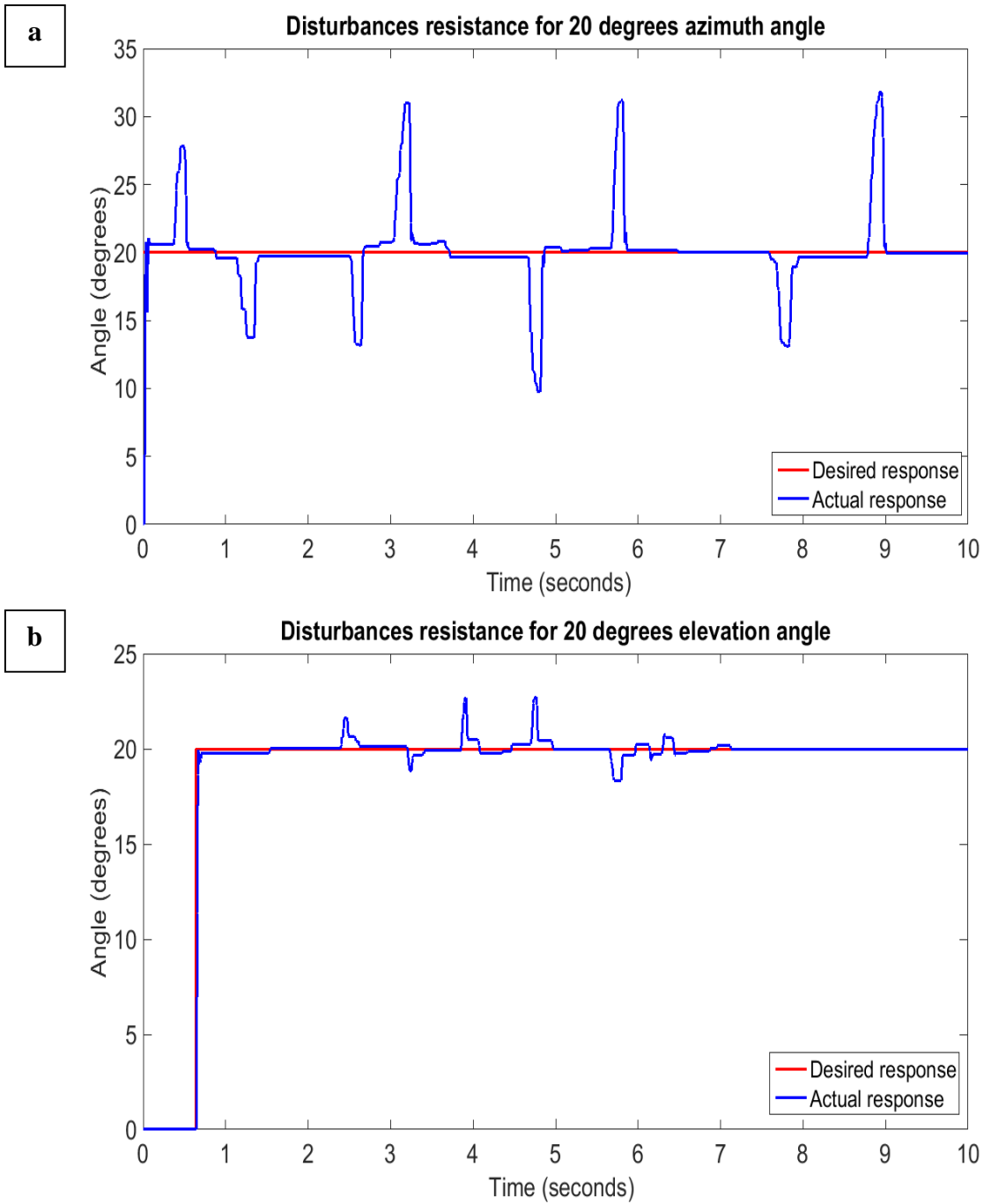


Figure 5.6: Disturbance resistance, a: azimuth, b: elevation

The system has been run for 20 degrees angle while subjected to disturbances to see how it resists and absorbs the disturbance by carrying back the system to the desired set point (figure 5-6). The disturbances were random so that the deviation from the set point is

proportional to how much strong disturbance was. And the time taken by the system to recover back its set point depends on how much far it was disturbed from its set point as well as the time between successive disturbances. Figure 5-6 tells that the system showed a very good resistance to the disturbances caused in both the azimuth and elevation subsystems.

5.3 Comparison of the results:

This section combines the results for each particular case of the simulation and real-time in one figure along with their desired response to make it easy for the observer to note out the similarity and the variation between them.

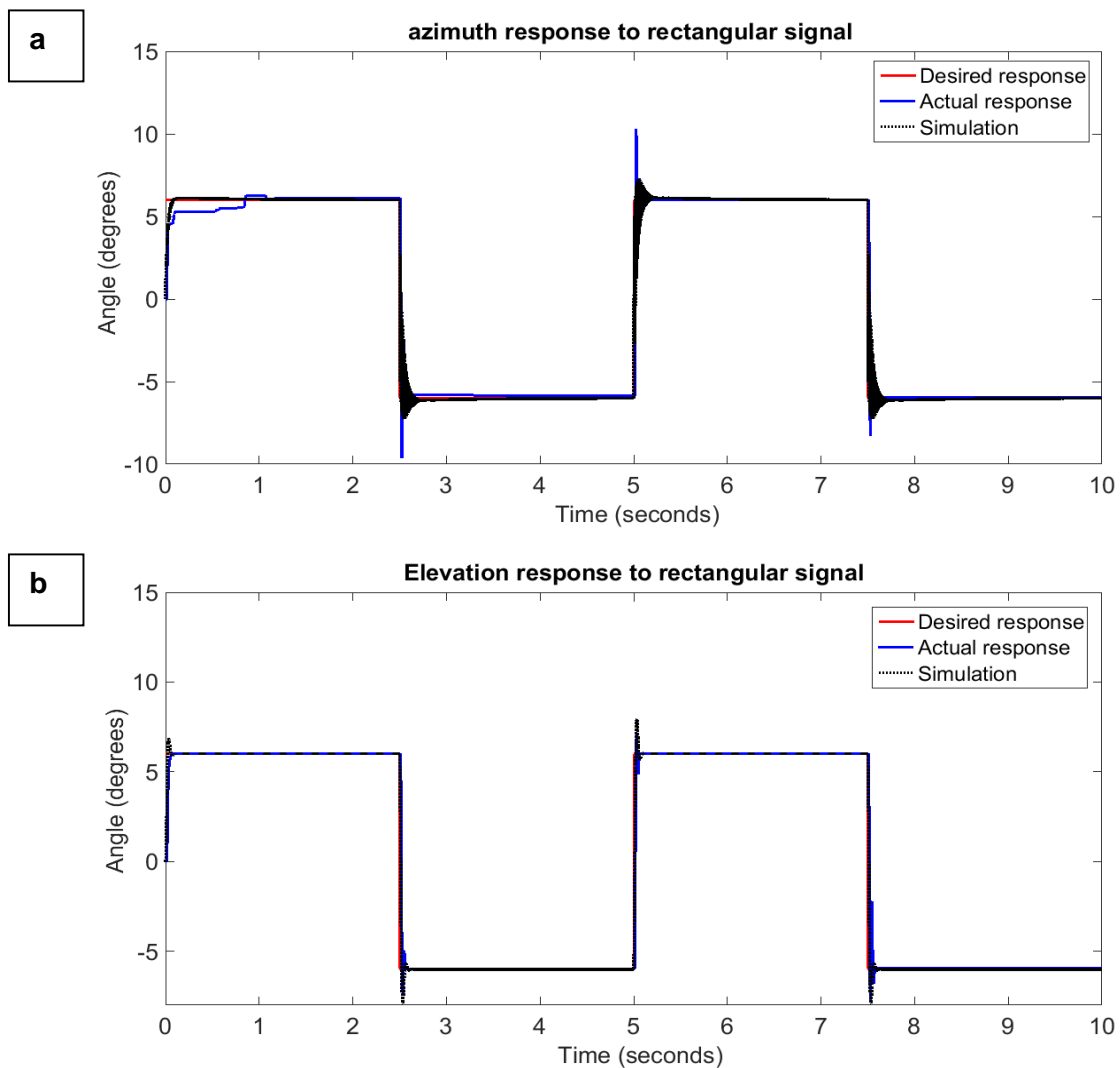


Figure 5.7: Simulation and real-time responses for rectangular signal, a: azimuth, b: elevation

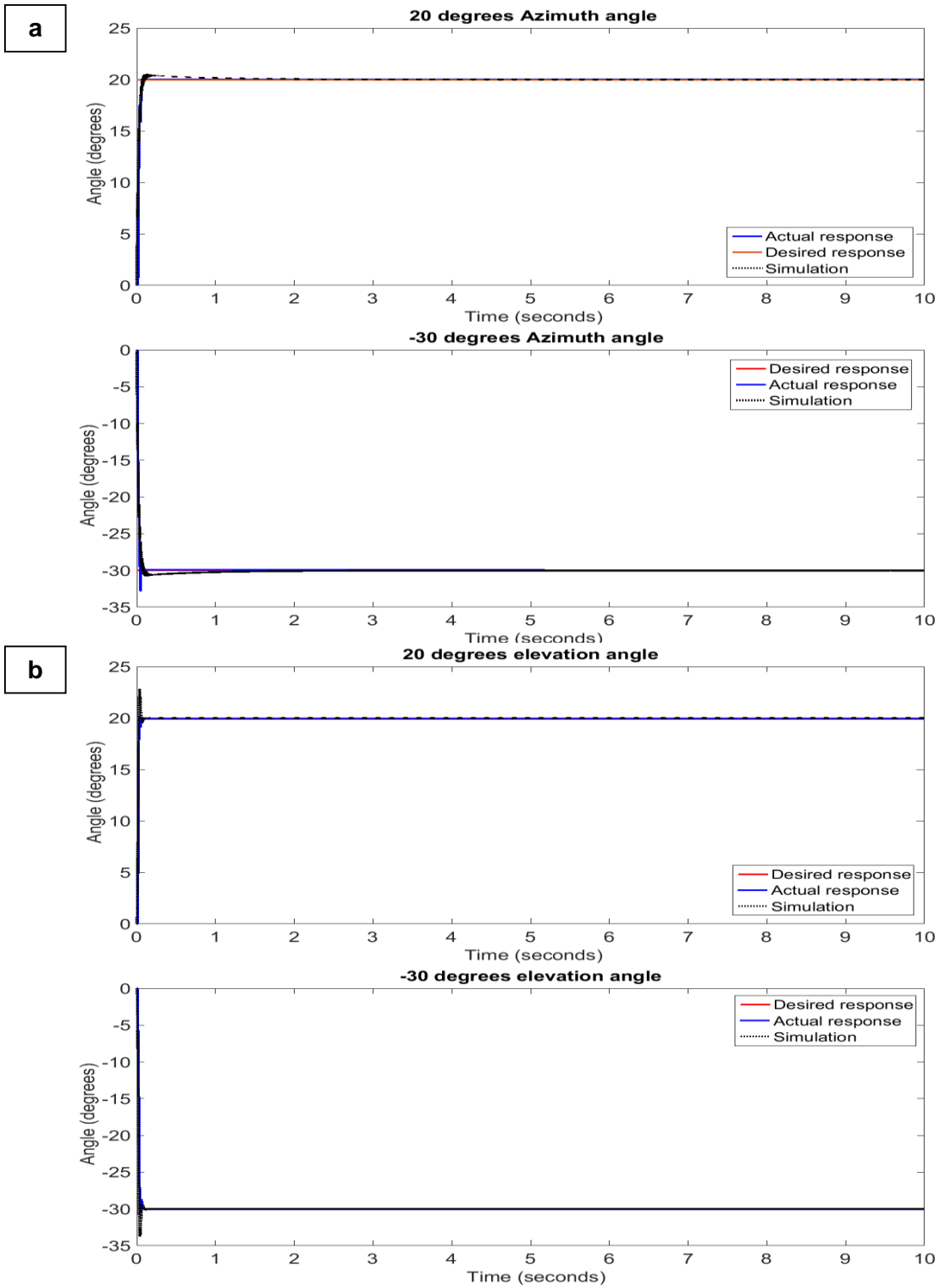


Figure 5.8: Simulation and real-time system responses to 20 and -30 degrees angles, a: azimuth, b: elevation

Figures 5-7 and 5-8 compare the simulated, actual and the desired responses which clearly show a big similarity between them all. From the figure 5-7 (the case of rectangular response) the responses of the simulated system seem to be similar in all corners of the rectangular function but the responses of the real-time system might be subjected to some variation due to the sudden load changes and the nonlinearities caused by friction, backlash, and some other factors.

Chapter 6

Conclusion and Future Work

6.1 Conclusion:

The objective of this thesis is to design an antenna position control system control for both the azimuth and elevation angles, using the PID controller as control algorithm.

The process of the design passed through many phases; initially, the system concept based on the previous case studies and related works is noted down; then the design has been visualized by simulating the frame of the system and its dynamic using Solidworks. Afterward, the real-time system is implemented by investing the idea earned from the simulated design.

Since the system is applying PID controller that requires knowledge about its transfer functions. The transfer function is needed to find out the PID parameters that can operate the real-time system safely without any hazards. For this reason, the process of the transfer function estimation is done by acquiring the data while the system was running in an open loop mode; the data collected from the input and output of the system using data logging feature in Matlab is exploited to estimate the transfer function. The estimated transfer function is used to design a Simulink model that contains PID controller block with PID tuning tool, which is the major tool for estimating the parameters of the PID controller in this study.

The PID controller parameters estimated from the process mentioned earlier are used to run the real-time system in different conditions to estimate its behaviour and monitor its accuracy in performing the desired commands. Also, the performance of the system under disturbances is tested. Commonly the system showed a very good performance for all the conditions under which it has been tested.

6.2 Future Work:

The design model has the ability to move the system to the desired position regardless of the real coordinates that the antenna is located on; in other words, we can say that the system moves to the angle command given by counting the degrees without consideration to any reference. Since the issue is like this, then the system can be developed further more by considering the real coordinates through attaching a compass or using GPS service by embedding the necessary accessories required for that. Also, the system can be improved to be a signal tracking system by finding out the strongest signal after scanning specific range.

The current system is using a PC screen to display its response in terms of graphs and that makes it works for academic purposes only. To upgrade the system so that it can run independently, the PC screen can be replaced by LCD screen that can show the response in digital format. For the purpose of running standalone system, two rotary encoders can be added as input keys through them the azimuth and elevation angles commands can be availed.

Furthermore, other control algorithms can be applied and comparative study can be carried out. In addition to that, some other programming methods can be used to enrich the academic and scientific value of the project.

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