# Self-steering Yagi-Uda antenna positioning system for television

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**ABSTRACT**

The aim of this study is to develop a prototype that automatically improves the position of a Yagi-Uda antenna using a microcontroller and to illustrate its radiation pattern through the use of MATLAB®. This study is intended for students and professors in the electronics engineering field. This served as their educational materials for teaching antenna system principles and theories. Developmental and experimental methods were used to achieve the objectives. The materials and components generally used in this study are a Yagi-Uda antenna, stepper motor, Arduino Uno, L293D motor shield, USB TV stick tuner, slotted optocoupler, ADS1115, coax cable splitter, speaker stand, and timing belt. The statistical tool used in this study was a Z-test to find out if the experiment results were significant. In testing the effectiveness of the automatic antenna system, the TV display in every increment of 1.8° was taken. It was the basis for the effectiveness of the study. At 5% α/2 level (1.96), the computed z value is 1.76, which is less than 1.96. Therefore, there is no significant difference between the picture quality of the TV display at every angle and the desired angle with maximum reception of the signal with the integration of MATLAB®.



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## 1. INTRODUCTION

Radio and television communication systems use antenna positioning systems. The antenna is basically used in receiving the primary television channels or radio stations. The antenna location significantly affects picking up signals [1]–[5]. A directional antenna has a more remarkable power of radiation in certain specific directions, which increases the antenna's performance in transmitting and receiving signals. Yagi-Uda antennas are directional antennas with higher performance than other types of antennas when considering the concentration of the signal's radiation. Yagi-Uda is a passive reciprocal device capable of transmitting and receiving electromagnetic energy [6], [7]. Yagi-Uda antennas are commonly used for the reception of signals in very high-frequency television [8]–[10]. Since it is a directional antenna, it has a folded dipole-driven element and some passive dipoles. These driven elements determine the position of the reflector and director of the Yagi-Uda antenna. The reflector is located behind the driven element at the back lobe of the Yagi-Uda antenna. In contrast, the director is in front of the folded dipole element in the direction where the major beam forms [11], [12].

The dipole serves as the main driven element in the design of the Yagi-Uda antenna. Other elements like parasitic elements can be added even without being connected to the dipole. The parasitic elements are responsible for picking up signals from the dipole and will re-radiate the signals focusing in one direction while eliminating the other signals. Putting up additional reflectors improves the performance of the Yagi-Uda antenna. It reduces the picking up of signals from behind the antenna [13]–[17].

The gain and directivity of the Yagi-Uda antenna are considered the advantages of the Yagi-Uda antenna over other types of antennas. Its gain receives even the lower strength signals. Its directivity minimizes the interference level of the signals. The Yagi-Uda antenna gain is of great importance because it enables all the transmitted power to be directed into the area where it is required, or when used for reception, it enables the maximum signal to be received from the same area. Yagi-Uda antennas have the most gain for their physical size compared to antennas like log periodic. It is cheaper than log-periodic because of its simplicity. It is easier to aim a Yagi-Uda antenna than some arrays because it is made of metal rods. It is also easy to mount on vertical poles with some positional fixings [18]–[23].

Sutherland *et al.* [24] stated that the fixed side of the cable limits the maneuverability of the positioning system and the positioned object. The common solution to the limitation on the rotation due to the twisting of the cable is to use a rotary joint or slip ring. The mechanism is immune to bending and unnecessary movement ensuing vibration. Furthermore, the positioning system allows for more than 180° movements. Dildar *et al.* [25] proposed a system that helps adjust the antenna's position. They used a smartphone with Android OS for remote operation and used two servo motors to move the dish antenna in the vertical and horizontal directions. The microcontroller controls the servo motor action. They conclude that it has to adjust manually to position the dish antenna to the precise angle to the maximum signal of a specific frequency.

Alhassan *et al.* [26] studied the relationship between the step-angle of the stepper motor and the satellite dish antenna diameter and beamwidth. They concluded that the stepper motor's step-angle limits the antenna diameter that can be used when we connect them directly and vice-versa. They also suggested that connecting the motor using gear to the antenna makes the design more flexible. In the study of Linderer and Dunkin [27], the similarities of the research study are that the user is enabled to select the desired signal, and the antenna automatically rotates to the appropriate position. However, their antenna positioning system includes an outdoor unit with a rotating antenna driven by a motor and an indoor unit connected to the outdoor via a communication link, such as a cable or a wireless link that enables the indoor unit to control the outdoor unit. The search procedure and repositioning of the antenna rely on accurate calibration of the antenna's angular velocity to determine the antenna's angular position rather than relying on a position sensor.

In the project by Choudhary *et al.* [28], the signal source is simulated by an infrared (IR) source and a corresponding IR receiver is used for signal detection. The tracking system has an antenna that contains a receiver, a delay circuit, and a base transmitter. Whenever the signal link breaks between the antenna and the satellite or source, the antenna revolves continuously in search of the signal. This system also has advanced connectivity with the monitor or liquid crystal display (LCD) screen, indicating the antenna position. This system was applied to monitor any attacking object and the missile launching system. In [29], the software controlling board used is an Arduino Uno R3 with a 5 V voltage supply from the USB port. The antenna system is equipped with a parallax five-position switch that controls and drives the ground plane's movement through the Arduino microcontroller. The 'five-position' is the push, up, down, right, and left parallax switch.

Other research studies have used MATLAB to simulate the full 3D radiation pattern of the antenna. The radiation pattern for every degree of the azimuth angle and elevation angle for both polarizations were sampled. The radiation pattern was sampled every 125 MHz. This results in a radiation pattern described by 2×73×360×180 samples [30], [31]. The similarities between this study and Hornback's version of the antenna positioning systems [32] are that both studies focus on automatically positioning an antenna. The difference between them is the type of antenna used and that Hornback used a microprocessor in his study, which is a very costly module, while this project used a low-cost module, the microcontroller. The microcontroller allows for 360° movement along the axis, thus tracking the radio wave's signal strength.

This study is intended for students and professors in the electronics engineering field. This served as one of the educational materials that were used for teaching principles and theories of an antenna. This also served as a reference to those with similar undertakings to the study. This study aims to develop an automatic antenna positioning system and illustrate the radiation pattern of the Yagi-Uda antenna with the integration of the stepper motor and microcontroller. The idea of providing such an automated device is essential in electronics engineering concerning antenna positioning systems. The software application to be used is MATLAB®, wherein the simulation of its radiation pattern must be shown. The self-steering Yagi-Uda antenna positioning system for television using MATLAB with the other related studies, it can be observed that most of the said studies were wireless and used remote control. Moreover, it used a stepper motor to position the antenna and MATLAB to view its radiation pattern, as this study also utilizes an automated control of the Yagi antenna positioning system. The proposed study can also utilize some of the processes involved in the previous studies.

## 2. METHOD

This chapter describes and discusses how the necessary data and information were gathered and used in the study. This also showed the procedure that analyzes the principles of the system. It also presented the materials that were used for the development of the design and construction of the study.

Developmental and experimental methods were utilized to achieve the study's objectives. The study was a developmental research method since the study focused on developing a prototype with the following steps: planning, designing, and identifying the appropriate components to be used, such as step-by-step construction, assembly, and experimentation. An experimental research method was implemented to test the system's effectiveness, accuracy, and functionality. The study conducted a series of experiments to determine how the system works and whether it is unstable or stable. Thus, making the system more accurate and effective.

### 2.1. Planning

The planning stage includes assembling ideas, data, and essential information needed. Using this gathered information, the study can provide valuable ideas for project construction. The planning stage gave a justifiable analysis of the proper steps to achieve one of the primary objectives of this study.

The preparation of choosing the suitable materials and equipment was considered for the efficiency of the project. Designing is the second part of the study resulting from the collected data. This part is also essential as this offers the order and the process of building the project with the desired output of the researcher. The study's electronic design was built from the electronic components' specifications. The circuit layout depended on the components' proper placement, programming, and organization.

Figure 1 shows the block diagram for the proposed system wherein the materials and the connections for each component. The power supply is needed for the motor driver. Arduino was the central controller in this system, where the stepper motor and the motor shield were connected. The Stepper motor was driven by the microcontroller and was responsible for the directional movement of the Yagi-Uda antenna connected to the television. MATLAB® GUI was incorporated to show the radiation pattern of the Yagi antenna.

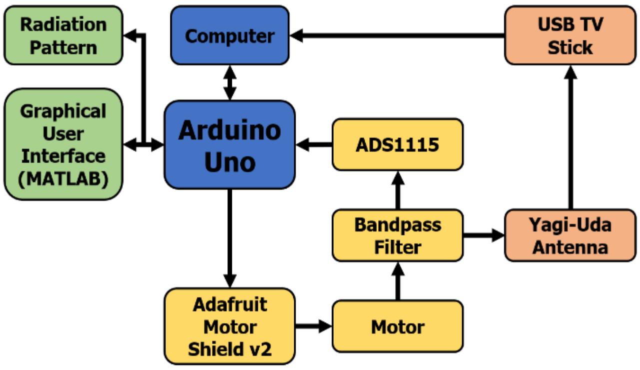


Figure 1. Block diagram of the proposed antenna positioning system composed of several components

### 2.2. Construction/development

This part pertains to the building, combining, and employing the data gathered and the materials into a process to make the system functional. This was the process of creating the system proposed in the study. The electronic parts were constructed using schematic and block diagrams, printed circuit board (PCB) fabrication, and component placement.

Electronic and hardware design: In this part, it was vital to study and analyze the design for the block diagram, schematic diagram, the proper placement of the components, PCB layout, and the final casing of the device. The connection between Arduino Uno and Adafruit motor shield was achieved through understanding the datasheets and existing literature. All of these aspects were considered in the completion of the project study.

Software procedure: The software components of this project were essential for the idea to be completed. In addition, the software is comprised of an integrated development environment explicitly used in programming the hardware in the system. The software application was MATLAB®, which displayed the radiation pattern of the Yagi antenna.

### 2.3. Validation and revision

Validation and revision were done after the construction of the project. This was to evaluate and assess its operation and functionality based on the design. This section defined the testing of the functionality of the device wherein a series of experiments and the system's repeated use were taken into account to detect errors, malfunction, and trouble in the system. If sudden errors occur, troubleshooting and revising the system are needed to fix the errors.

### 2.4. Evaluation

After the testing and revision process of the system, it is a must to analyze and evaluate the system's data to determine if the data gathered meets its desired objectives, its efficiency, and the effectiveness of signal strength received by the system. The determining factor or criteria numerically depended on the conduct of statistical tools. This study considered and applied several statistical tools to the gathered data.

Here is the statistical treatment. The statistical tools used in this proposed study were the Z-test to determine if the experiment results were significant. The consistency of the Yagi antenna in getting and receiving the maximum signal strength, the time it takes for the antenna to be positioned to the desired angle, and if there are faults in the movement of the stepper motor determine the accuracy and efficiency of the system. Z-test was used to evaluate the accuracy of the system. It tested 45 trials to know the system's accuracy. The formula for the Z-test is presented below with $\hat{p}_1$ and $\hat{p}_2$ as the sample proportions, $n_1$, and $n_2$ as the sample sizes, and $\hat{p}$ as the total pooled proportion.

$$Z = \frac{(\hat{p}_1 - \hat{p}_2) - 0}{\sqrt{\hat{p}(1-\hat{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \tag{1}$$

## 3. RESULTS AND DISCUSSION

This chapter discusses the steps to achieve the objectives of the study. It also presents the design of the prototype, construction, and assembly of the mechanism of the system. Moreover, it includes the results during a series of experiments and testing, the problems encountered, and the interpretation and analysis of the data acquired in order to test the functionality and accuracy.

### 3.1. Design

The prototype design was connected to the concepts and principles gathered from the related kinds of literature and studies in planning for the construction of the prototype. There are three major processes in the actual construction of the prototype. These are the electronic assembly, the casing assembly, and the program assembly. Electronic assembly includes the proper placement of the components. For the casing assembly, the tripod was used as the base of the antenna system, as reflected in Figure 2, while the program assembly included the making of the MATLAB® GUI.

Figure 2. Final prototype of the study incorporating conceived ideas from planning and designing

Figure 3 shows the proponent's MATLAB graphical user interface design. The polar pattern command in the MATLAB® was used to display the antenna pattern. The parameters included are the port number received voltage in mV, received power in dBm, and angle in degrees. The home position is to set the antenna initially at 0°, and the scan port is to recognize the software MATLAB® to the Arduino.

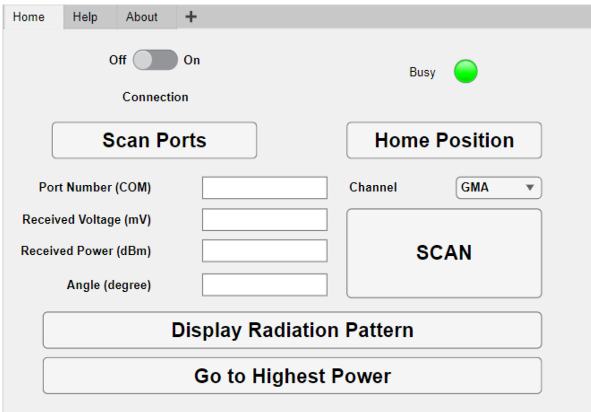


Figure 3. The home graphical user interface of the system programmed through MATLAB®

### 3.2. Construction and assembly

Analyzing the design is vital for the system's effectiveness and accuracy in construction and assembly. While constructing and assembling the antenna system, problems were encountered, such as that the first procured motor shield could not be recognized through MATLAB. Thus, the Adafruit motor shield v2 was incorporated so that the MATLAB® could read it.

Another problem met was on the coax wire, where the antenna twists and turns 360° counterclockwise every time to get the maximum reception of the signal. Therefore, it is necessary to rotate the antenna at 180° horizontally in the counterclockwise direction, then turn it to 360° clockwise and start scanning starting from -180° until it returns to its home position. This mechanism can cover the necessary area to gather the signal strength. In addition, the lightweight Yagi-Uda antenna was built up on a tripod and used as its base. The green and red-light emitting diodes (LEDs) are located on its body, which serve as indicators. The green light is used as a signal when the system is a "connected" and "busy" signal, meaning it is in the scanning process.

In order to illustrate the radiation pattern, the MATLAB® graphical user interface (GUI) for the antenna radiation pattern was developed. After the scanning process of 360°, a message prompt appeared, stating the maximum gain in decibels and its specific angle. After the message prompt, the user clicked the "Display Radiation Pattern" to view the radiation pattern. The parameters that were found in the radiation pattern were: gain at a certain angle, half-power beamwidth (HPBW), first null beamwidth (FNBW), front-to-back ratio (F/B), side lobe level (SLL), main and major Lobe of the Yagi-Uda antenna.

### 3.3. Testing

In order to test the effectiveness of the automatic antenna system, a series of experiments were conducted. The TV display in every increment of 1.8° was taken and was the basis for the effectiveness of the study. There were 45 trials done that were broken down into 15 trials per channel (S&A, GMA, and ABS-CBN). Furthermore, the test was conducted outdoors and near the TV transmitter towers. Figure 4 is a TV display sample where the Yagi-Uda antenna was in its desired angle position at 82.8 degrees while Figure 5 is a sample radiation pattern displayed in the MATLAB® GUI.


Figure 4. Sample TV display with the highest received signal at 82.8 degrees

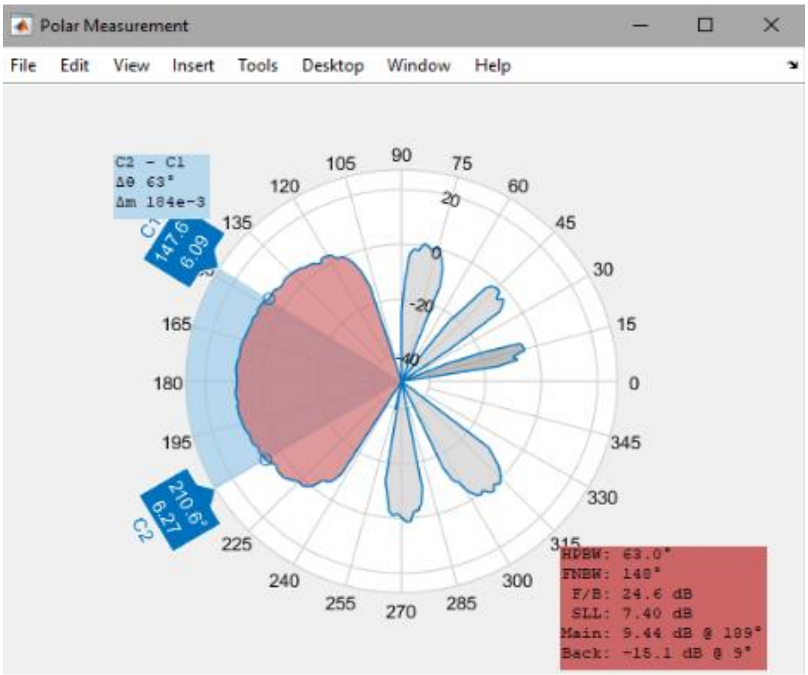


Figure 5. Sample representation of radiation pattern displayed through the developed GUI from MATLAB®

#### 3.3.1. Statistical result

The result of the data analysis using the Z test stated that the null hypothesis was not rejected. The 5% $\alpha/2$ level was chosen for a 95% confidence level with a value of 1.96. The computed z value is 1.76, which is less than 1.96. With the statistical result given, the null hypothesis is accepted. This means that there is no significant difference between the picture quality of the TV display at every angle and the desired angle with maximum reception of the signal. The statistical result shows that the study has been successful and desirable.

## 4. CONCLUSION

The researchers have created an automatic antenna system using MATLAB® that illustrates the antenna's radiation pattern. The researchers made it automated using mainly a stepper motor, Arduino Uno, and a program coded from MATLAB®. This system is also suitable for other educational purposes relating to antenna theories and development. After a series of trials of the system, the researchers concluded that there was a consistency in the radiation pattern in every channel. The reflection of signals in buildings and structures, also known as multipath fading, affects the frequencies across a given channel and the reception of the signal. Therefore, the radiation pattern tested indoors is not the same as the outdoor testing. Each time the location area of the receiving antenna is near the transmitter antenna, the reception of the signal is evident.

## 5. RECOMMENDATION

The following recommendations were suggested based on the findings and conclusions. Increasing the channels' resolution for smooth radiation pattern illustrations. Any other terrestrial antenna (i.e., log-periodic) can be used except the satellite dish antenna. A manual stop can also be added for additional study features in case the user is contented with the picture quality of the TV display at a specific angle of position of the antenna. Three to five maximum angles should be assessed to get the consistency of the radiation pattern. To assess the accuracy of the radiation pattern, compare the actual with the theoretical radiation pattern.

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