Antenna Tracker System for Unmanned Aerial Vehicles: A Short Review

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***Abstract*— Unmanned Aerial Vehicle (UAV) is a modern technology used to perform difficult and dangerous aerial missions that cannot be carried out by manned aerial vehicles. Ground Control Station (GCS) is a system that manages all the parameters of the UAV. GCS and UAV communicate using radio waves through telemetry, which functions to transmit and receive flight data. Antenna tracker is a device used to connect the GCS (Ground Control Station) and the UAV (Unmanned Aerial Vehicle). The antenna tracker works by performing tracking to direct the antenna towards the UAV. Nowadays, there are various forms of antennas used in telecommunication technology. Each type of antenna has its own radiation characteristics, some are directional, while others are more omnidirectional. Directional antennas are the right choice to be used with an antenna tracker. Generally, directional antennas have a narrow radiation range but a relatively long transmission distance. This paper provides a review of the state-of-the-art in antenna tracker technology for unmanned aerial vehicles (UAVs), with a focus on design, performance, and type of antenna. The study involved a literature search of various databases. The design approaches for antenna tracker systems range from simple single-axis trackers to sophisticated dual-axis trackers with pan-tilt mechanisms, and type of antenna such as helical were explored. The study concludes that antenna trackers have numerous applications in various industries, including military, agriculture, and surveying, and the demand for reliable and accurate antenna trackers is expected to continue to grow with the increasing popularity of UAVs.**

***Keywords*—Antenna, GCS, tracker, UAV**

I. Introduction

Unmanned Aerial Vehicle (UAV) is a modern technology used to perform difficult and dangerous aerial missions that cannot be carried out by manned aerial vehicles. UAV is defined as a pilotless powered aircraft that is controlled remotely. [1]

Ground Control Station (GCS) is a system that manages all the parameters of the UAV. GCS is used to monitor the movements and obtain information from the UAV that is carrying out a mission. [2] GCS and UAV communicate using radio waves through telemetry, which functions to transmit and receive flight data. [3] Generally, the working frequency used in telemetry is 433 MHz and 915 MHz. [4] The antenna model commonly used is the omnidirectional antenna model, which spreads its signal in all directions. Unfortunately, this antenna model cannot reach a far distance. [5]

Antenna tracker is a device used to connect the GCS (Ground Control Station) and the UAV (Unmanned Aerial Vehicle). The antenna tracker works by performing tracking to direct the antenna towards the UAV. The antenna model used is a bidirectional antenna model, which focuses its signal in one direction. This focus allows the signal of this antenna model to have a very long range. [4] [6]

Antenna tracker systems play a crucial role in maintaining reliable communication between unmanned aerial vehicles (UAVs) and their ground control stations. [7] This paper provides a review of the current state-of-the-art in antenna tracker technology for UAVs, focusing on design, performance, and type of antenna.

II. Methods

The method used in this paper involves conducting a literature review of various journals regarding different antenna forms. After understanding the various commonly used antenna shapes, further discussions are carried out regarding antennas suitable for antenna tracking purposes by examining the antenna radiation patterns.

III. Results and Discussion

A. Type of Antennas

Nowadays, there are various forms of antennas used in telecommunication technology. Each type of antenna has its own radiation characteristics, some are directional, while others are more omnidirectional. The design of the antenna itself has a significant impact on the system performance. The form of the antenna is adjusted to its specific usage needs.

1) Wire Antennas

Wire antennas is the oldest, simplest, cheapest, and versatiles for many applications. Fig. 1 illustrates the several forms of wire antennas, including the straight wire (dipole), loop, and helix. Loop antennas are not limited to circular shapes; they may also be shaped like a square, elliptical, rectangle, or any other shape. However, because to its straightforward fabrication, the circular loop is the most

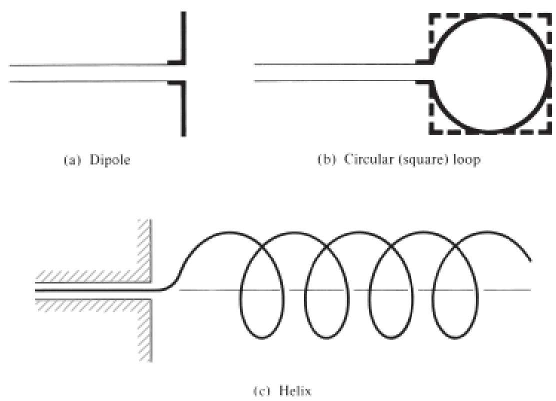

Fig. 1. Wire antennas [8]

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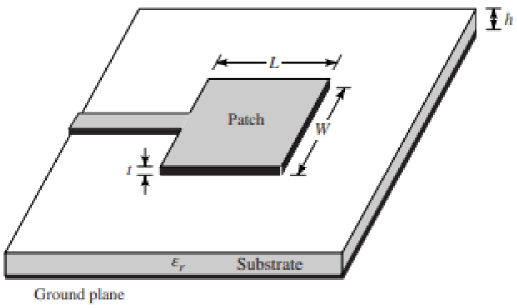

Fig. 2. Microstrip antennas [8]

widely used. [8] [9] [10] An engineer typically searches for an existing design that has the desired electromagnetic characteristics. If this structure has an analytical expression that precisely predicts its performance, the engineer uses it to find the optimal parameters. This design technique has produced many different antenna designs. [11]

2) Microstrip Antennas

Microstrip antennas are composed of a grounded substrate with a metallic patch, which can have various configurations. Rectangular and circular patches, on the other hand, are the most often utilized because they are easy to produce and analyze and have desired radiation properties, such as minimal cross-polarization radiation. [8] Fig. 2. Show the rectangular microstrip antennas. These antennas have a low profile and can conform to both planar and nonplanar surfaces. They are also inexpensive to fabricate using modern printed-circuit technology and are mechanically durable when attached to rigid surfaces. Additionally, they work well with MMIC designs and are highly adaptable in terms of resonant frequency, polarization, pattern, and impedance. [13] [14]

3) Aperture Antennas

Aperture antennas can come in different shapes, such as waveguides or horns, and have apertures that can be square, rectangular, circular, elliptical, or other forms. [12] The example of the form shown in Fig. 3. These types of antennas are useful for space-related purposes since they can be conveniently mounted on the surface of an aircraft or spacecraft. [8]

4) Array Antennas

Some applications require specific radiation characteristics that cannot be achieved using just one antenna element. An array of radiating elements arranged electrically and geometrically may be able to achieve the desired radiation characteristics that a single element cannot provide. The array antennas shown in Fig. 4. The arrangement of the array can be designed to produce a maximum radiation in specific directions, minimum radiation in other directions, or any other desired radiation pattern through the addition of radiation from the elements. [8] [15] Communication systems frequently employ antenna arrays because they provide improved data quality due to their increased directivity and antenna gain, as well as a higher signal to noise ratio (SNR). Also, antenna arrays can adjust the antenna radiation pattern to follow the transmit/receive antenna’s direction. [16]

5) Reflector Anntenas

Reflector antennas, in various forms, have been utilized since Hertz's discovery of electromagnetic wave propagation in 1888. The main function of a reflector antenna is to concentrate or emit most of the electromagnetic energy across its opening into a focal plane or far field for communication or energy transfer. [17] The reflector antennas shown in Fig. 5. Antennas of this variety have been constructed with diameters exceeding 305 meters, or even larger, to attain the high gain necessary for transmitting or receiving signals that have traveled millions of miles. [8] The size of the antenna is crucial in achieving this goal. In addition to the parabolic reflector, there is another type of reflector, known as the corner reflector, which is not as widely used. Reflector antennas can be used to transmit and receive signals to communicate over great distances, had to travel millions of miles.

6) Lens Antennas

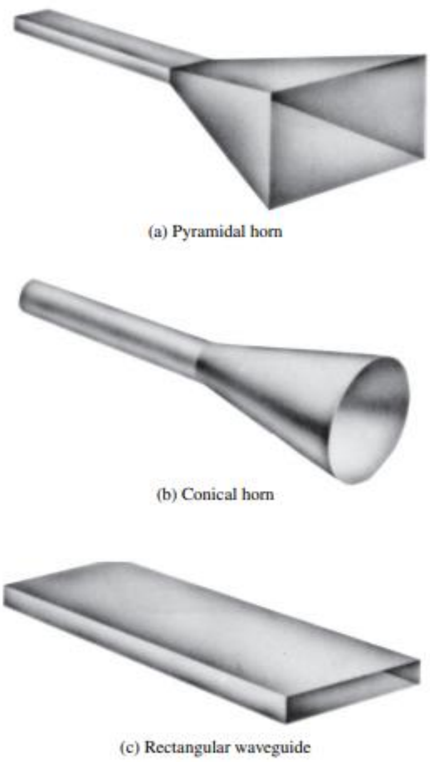

Fig. 3. Aperture antennas [8]

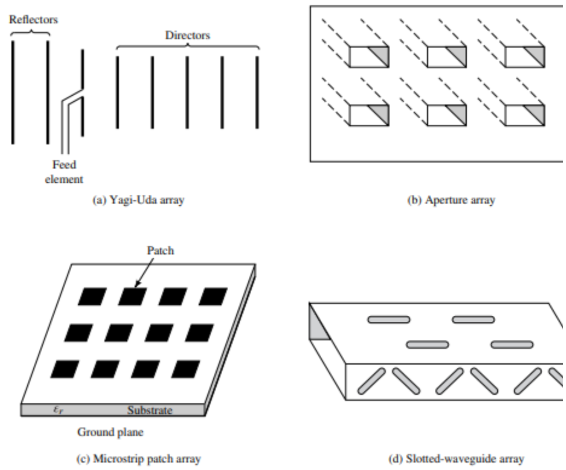

Fig. 4. Array antennas [8]

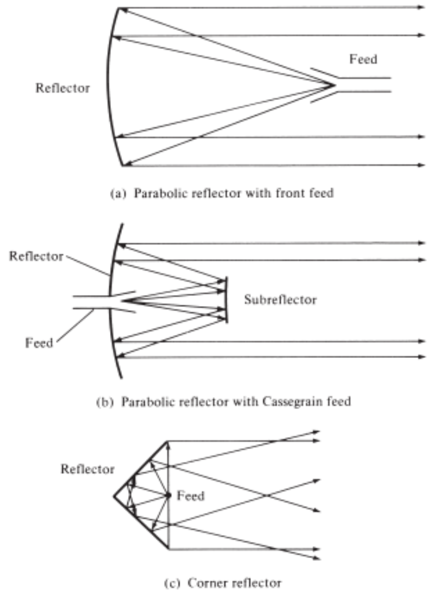

Fig. 5. Reflector antennas [8]

The main function of lenses in antenna technology is to focus divergent energy and prevent it from spreading in unwanted directions. The lenses' geometrical design and material can be manipulated to transform various types of divergent energy into plane waves. [8] They are often used in similar applications as parabolic reflectors, particularly at higher frequencies, but their size and weight can become impractical at lower frequencies. Lens antennas are categorized based on their material composition or geometric shape. The lens antennas shown in Fig. 6.

B. Antennas Used for Antenna Tracker

Generally, there are two types of antennas based on their radiation characteristics, omnidirectional and directional. Omnidirectional antennas radiate in all directions, providing a 360 degree radiation pattern, while directional antennas radiate in only one direction with a range of 45 to 90 degrees radius. [18]

Antenna tracker is used to connect GCS with UAVs that are located far away, requiring an antenna with a long transmission distance. Directional antennas are the right choice to be used with an antenna tracker. Generally, directional antennas have a narrow radiation range but a relatively long transmission distance. [19] Examples of antennas that belong to the directional antenna category are helical antennas, horn antennas, patch antennas, and Yagi-Uda antennas.

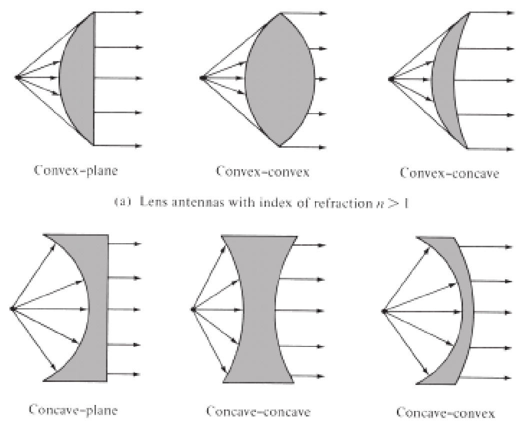

Fig. 6. Lens antennas [8]

1) Helical Antenna

A fundamental geometric form with uses in many branches of engineering and physics is the helix. The coil spring, often known as a helix, is a typical and identifiable structure in mechanical systems. Similar to this, helical conductors, sometimes known as inductors, are a common kind of circuit element in electrical systems. The helix has been used as a beam antenna recently. [20]

In the study of the electromagnetic field around a helix, two perspectives can be taken: (1) a field which is guided along the helix, and (2) a field which radiates. For this discussion, these two perspectives will be considered separately. From the first perspective, it is believed that an electromagnetic wave can be transmitted without any weakening along an endless helix in a similar way to transmission lines or waveguides. This method of transmission is called the transmission mode and various modes of transmission are possible. [20]

By adjusting the size of the geometrical properties of the antenna relative to the wavelength, its radiation characteristics can be altered. The input impedance is mainly affected by the pitch angle and the size of the conducting wire, particularly near the feed point, and can be modified by manipulating their values. Although the antenna generally has elliptical polarization, circular and linear polarizations can be attained across different frequency ranges.

The helical antenna has multiple operational modes, but the primary ones are the broadside (normal) and end-fire (axial) modes. [8]

When operating in the normal mode, the antenna radiates a field that is strongest in a plane perpendicular to the helix axis and weakest along the axis itself. which depicts a figure-eight shape rotated around its axis, resembling that of a linear dipole of $l < \lambda_0$ or a small loop ($a \ll \lambda_0$). To achieve the normal mode of operation, the dimensions of the helix are usually small compared to the wavelength (i.e., NL0 $\ll$ λ0). Fig. 7. display radiation patterns for normal mode.

A more practical mode of operation is the axial or end-fire mode, which can be easily generated. In this mode, there is only one primary lobe and its highest radiation intensity is along the helix axis. The smaller lobes are at angles to the axis. To activate this mode, the diameter D and spacing S must be relatively large compared to the wavelength. To achieve

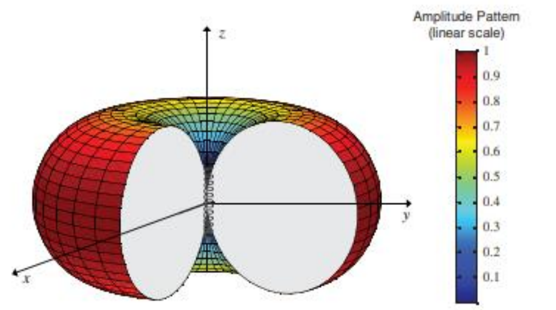

Fig. 7. Three-dimensional normalized amplitude linear power patterns for normal mode helical antenna [8]

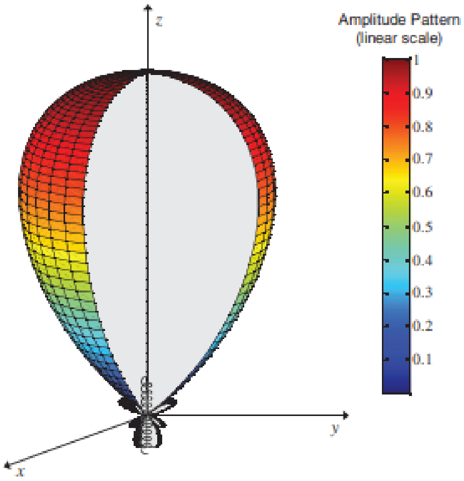

Fig. 8. Three-dimensional normalized amplitude linear power patterns for axial mode helical antenna [8]

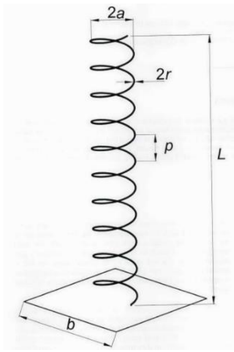

Fig. 9. Helical Antenna [21]

circular polarization, primarily in the major lobe, the circumference of the helix must be in the $\frac{3}{4} < C/\lambda_0 < \frac{4}{3}$ range (with $C/\lambda_0 = 1$ near optimum), and the spacing about $S \simeq \lambda_0/4$. The pitch angle is usually $12^\circ \leq \alpha \leq 14^\circ$. Fig. 8. display a radiation pattern for axial mode.

Helical antennas are typically placed above a conducting ground plane. The helical antenna is fed by a generator that is connected to the base of the antenna. The feed of the helical antenna is usually located at the edge of the conductor axis cylinder. [21] The helical antenna shown in Fig. 9.

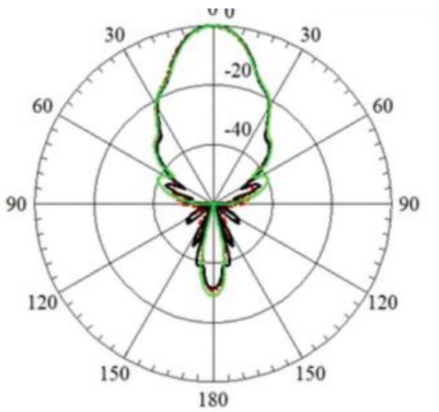

Fig. 10. H-plane far-field amplitude patterns [8] [21]

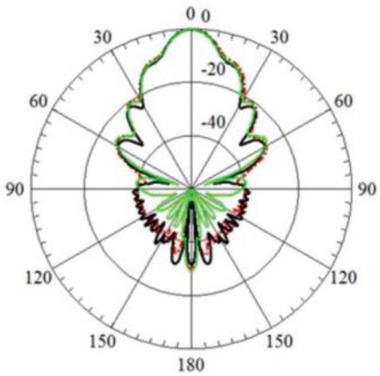

Fig. 11. E-plane far-field amplitude patterns [8]

In the helix model, the antenna begins with a cable of length 3r or 3 times the cable width. The radius of this cable greatly affects the input impedance. We can view the shape of the helix as a transmission line. The number of turns on the antenna represents series inductance. Meanwhile, the capacitance between two conductors in one turn. [22]

To follow the traditional design guidelines, the helical antenna operates in the axial mode within the frequency range of $3/4 < C/\lambda < 4/3$. The wire diameter (d=2r) doesn't significantly impact the antenna characteristics within the range of $0.005 < d/\lambda < 0.05$. Empirical research has determined that the optimal pitch angle falls within a relatively narrow range of $12° < \alpha < 14°$ degrees. The antenna gain varies with frequency within the operating band, with maximum gain near the upper edge of the range (i.e., $f_c < f_p < f_{max}$), when $C/\lambda_p = 1.1\text{-}1.2$. The minimum number of turns for the antenna is around N = 4. The shape and size of the ground plane are not crucial, and square or circular flat plates are typically used, with the minimum square size (or the minimum circle diameter) being $b/\lambda_c = 0.75$.

2) Horn Antenna

The simplest type of antenna structure is likely to be conical horns, which are relatively small in size when producing moderate antenna gains of about 20 db. However, as the power gain increases, the length of the horn will also increase, which can become a problem due to its excessive length. Conical horns often have gain and directional properties that are quite comparable to those of rectangular or pyramidal horns in this regard. Conical horns are particularly helpful as antenna gain standards as their physical dimensions allow for the easy calculation of the axial gain. [23]

The horn is a popular component used to supply signals for various applications such as large radio astronomy, satellite tracking, and communication dishes. It is also commonly used in phased arrays and serves as a standard for measuring the gain and calibration of high-gain antennas. Its popularity is due to its simple design, easy activation, versatility, high gain, and overall excellent performance.

The effective area A_{eff} of an antenna is

$$A_{eff} = \frac{g\lambda^2}{4\pi} \quad (1)$$

where g is the absolute power gain and λ the free-space wavelength. The effective area of an antenna is equal to the actual aperture area A if its intensity distribution, polarization, and phase are all uniform throughout the aperture. An antenna's effective area is often represented in relation to its actual area, as a ratio A_{eff}/A. The aperture area of a conical horn is

$$A = \frac{\pi}{4} {d_m}^2 \quad (2)$$

And the ratio

$$\frac{A_{eff}}{A} = \frac{g}{\pi^2 \left(\frac{d_m}{\lambda}\right)^2} \quad (3)$$

Fig. 10. and Fig. 11. Show the amplitude power of horn antenna

3) Patch Antenna

Microstrip patch antennas (MPAs) are fabricated by placing a conductor on a substrate backed by a ground plane. While they can be made in different shapes, the most common designs are circular and rectangular patches are the ones that are widely used, since their design procedure is simple and well developed. The following are some of the benefits of using MPAs: (i) they are easy to design because they have undergone extensive research and theory; (ii) their planar geometry facilitates easy fabrication and integration with other electronic devices; (iii) they can be fabricated on a variety of inexpensive substrates, making them a cost-effective option for many applications; (iv) they are low profile and rugged, making them perfect for use in a number of practical applications, such as in GPS receivers, tablets. [8] Fig. 12. Show the radiation pattern of rectangular microstip patch antenna.

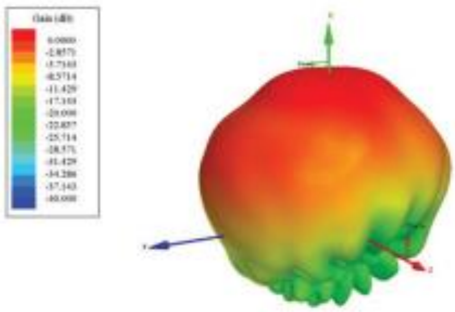

Fig. 12. 3D pattern of radiation rectengular microstrip patch [8]

4) Yagi Uda Antenna

The Yagi-Uda antenna is an antenna with a dipole array system and several closely spaced elements. in the yagi uda antenna, the dipole works as a driven element, while the other elements work as reflectors. The array has a single element that receives input, called the driven element as shown in Fig. 13. The other elements are not fed directly but interact with the driven element. A reflector is behind the driven element and some directors are in front of it. These elements are not fed but help shape the radiation pattern. [24] The main direction of radiation for yagi antennas is perpendicular to the dipole and on the same plane as the elements. The radiation starts from the reflector and passes through the driven element and the director. [25]

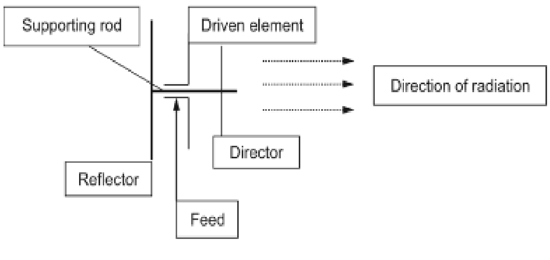

Fig. 13. Element of yagi-uda antenna [24]

C. Antenna Tracker Overview

Various design approaches for antenna tracker systems were presented in the reviewed studies, ranging from simple single-axis trackers to sophisticated dual-axis trackers with pan-tilt mechanisms.

Antenna tracker requires several main components fot its creation, including:

- Microprocessor
- IMU Sensor
- Gyro Sensor
- GPS

All the components mentioned above can be found in a 32-bit microcontroller device commonly called a flight controller shown in Fig. 14.

To generate high torque, a gear transmission was employed along with a servo motor actuator to move the mechanical components of the antenna tracker in the azimuth axis (yaw) through a 360-degree movement and in the elevation axis (pitch) through a 180-degree movement. [26]

Proper radio and telemetry configuration is necessary to operate the antenna tracker, with the GCS, antenna tracker,

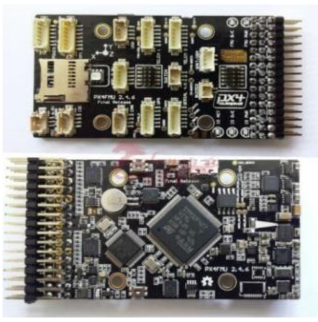

Fig. 14. Flight Controller [4]

and UAV needing to be configured correctly. In order to prevent interference from telemetry radio signals, telemetry configuration was performed. Two pairs of telemetry radio with different frequencies were utilized. The frequency of 433 MHz was used for the telemetry radio between the GCS and the antenna tracker, while the telemetry radio between the antenna tracker and the UAV utilized a frequency of 915 MHz. [4]

TABLE I. AUTHOR AND THEY RESULT

No.	Author	Result
1	Gesang Nugroho, Dicky Dectaviansyah	They used a 6 dBi 3 element yagi uda and 2.1 dBi omnidirectional antenna. The result is that it can perform tracking with an average error of 5.62° on the Azimuth axis (Yaw) and 1.51° on the elevation axis (Pitch). [4]
2	Rifqi Firmansyah, et al	Developed a weather monitoring system with an antenna tracker using a biquad antenna. In the design process, he added a buffer to generate a maximum signal shot. This is needed to reduce losses when transmitting and receiving data from the transmitter and receiver. The result is the system can transmit and receive data in real time at up to 12170.1 meters in height, starting at 23.8 meters. Since this atmospheric layer has the greatest influence on weather conditions on the surface of the planet, the system was successful in obtaining the atmospheric parameter data required for weather observations in the troposphere (6–10 km) to the tropopause (10–20 km). [27]
3	Ahmad Riyandi, et al	Proposed a method to tuning a GPS-based antenna tracker using fuzzy logic. They used a 433 MHz Yagi-Uda antenna because it has a directional radiation pattern. The outcome was that the antenna tracker system could follow an object's movement and respond to it more effectively. Up to 60 kmph might be reached by the system while following the item. [28]
4	Febi Almetania, Yasdinul Huda	Design an antenna tracker as a post-disasater monitoring media used a biquad antenna. The result is antenna tracker quite accurate to track a UAV with angle difference 15° between antenna tracker and UAV. it only takes 2 to 3 seconds to equalize the position from the difference in angle. The biquad antenna can reach UAV with the fartest distance at 4.6 KM. [29]
5	Awang Bayu Nugroho	Design a smart measurement for long rancge communication with antenna tracker. He opted for a biquad antenna because it is tolerant of a lot of error. The result is antenna tracker are worked with unaccurated value in measurement the distance using 2 GPS sensors. [30]

IV. CONCLUSION

Antenna trackers are vital components of UAV communication systems, ensuring a stable and reliable link between UAVs and their ground control stations. This review paper provides an overview of the current state-of-the-art in antenna tracker technology, covering design, performance, and autonomous control aspects. Future research directions include the development of lightweight and compact trackers, the integration of multiple sensors for more accurate positioning, and the use of advanced machine learning algorithms to improve tracking performance

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