Angle of Arrival Using Cross Yagi-Uda Antennas

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Abstract—this paper discusses Angle of Arrival method using cross Yagi-Uda antennas. The method is based on ratio of signal strength from receives of nine cross Yagi-Uda Antennas. Just little research explores the potentials of radiation pattern of Yagi-Uda antennas to estimate Angle of arrival. The proposed method is using radiation patent of nine Yagi Uda antennas that is placing on different direction. The Antennas that have same direction as the signal emitter reach highest signal strength. Based on ratio between highest signal strength of ones antennas received and its neighborhood signal strength, the azimuth and elevation angle of arrival can be calculated. The performance of our method is investigated by simulation of AOA method using cross Yagi-Uda Antennas.

Keywords—angle of arrival, azimuth and elevation angle, cross Yagi-Uda antennas, ratio signal strength

I. INTRODUCTION

Determining azimuth and elevation angle of arrival from source of the radio emission is great importance for retrieving the position of objects. Various methods have been produced such as Received Signal Strength (RSS) [1] - [4], Time Difference of Arrival (TDOA) [5] - [6], Difference Phase of Arrival (DPOA)[7], Difference of Arrival (DOA)[8] and Angle of Arrival (AOA)[9]. AOA methods have not been fully studied to estimate the azimuth and elevation angles simultaneously.

AOA methods have been developed such as use of Omni directional antenna array which is arranged in a circular to the ESPRIT method for estimating the direction of emission sources [8]. The uses of beam lobe (radiation pattern) directional antennas have not been much explored. It can be found in the use of beam lobe for AOA study [10]. This method can be used to fly at low speed vehicle but will find it hard to follow the movement of a vehicle flying at high speed like a rocket.

The use of the radiation pattern of Yagi antenna has also been studied by Sayrafian-pour and Kaspar [6]. In his research revolves Yagi antennas are used at the receiver and transmitter. Transmitting antenna rotated 360 degrees to each movement of the receiving antenna Θ degrees. The method is applied to determine the position of the emission sources in a building. The method is claimed to have better results than the use of MUSIC and ESPRIT algorithms [9]. Potential use Yagi antenna for AOA methods have the opportunity to study further. Exploration of the use polaradiasi Cross Yagi-Uda antenna in azimuth and elevation angle estimation simultaneously has never been done. This paper will discuss the use Yagi-Uda antenna Cross to estimate the azimuth and elevation angles simultaneously.

II. METHODOLOGI

A. Received Signal Model

Powerful radio signal that is captured by the receiver of a radio transmitter at a certain point is modeled by Bahl and Padmanabhan [1] with equation (1).

\[ P(d)[dbm] = P(\text{do})[dbm] - 10n \log\left(\frac{d}{\text{do}}\right) - nW \ast \text{WAF} \eta W < C \]

\[ C \ast \text{WAF} \eta W \geq C \]  

Where n is the path loss by an increase in the distance P (do) is the signal power at the reference distance and d is the distance between the transmitters to the receiver. C is the maximum number of reflections that can infer the magnitude of the received signal strong. nW is the number of reflections between the transmitter and the receiver, and the WAF is the attenuation factor of the barrier.

B. Model of Cross Yagi Uda

Yagi-Uda antennas are cross Yagi antennas that have a cross-shaped element. Fig. 1 shows the physical appearance of cross Yagi antenna and Fig. 1b shows the radiation pattern.

(a) Physical appearance of Cross Yagi-Uda
The composition of cross Yagi antennas is created using a 3x3 configuration. Each antenna has different direction angles. Figure 2 shows the configuration of Cross Yagi-Uda antennas used.

**Figure 2.** Configuration of nine Yagi-Uda antennas

Fig. 2 shows nine CrossYagi-Uda antennas with different direction angles. Antenna 1th amplifies the signal received (rx) with the gain \( G(\alpha - sa, \beta) \) because the antenna is directed at a different angle then the amplified signal is received in accordance with the received antenna gain angle. Nine antennas assumed have the same radiation pattern, so that the radio signals that come in will be strengthened by each antenna. If the antennas are arranged horizontally directed to different direction angles of \( sa \) and vertical antennas are arranged with different directions of \( sb \), then signal strength will be received and the equation can be written as follows:

\[
rx = St + nW
\]

\[
P_k(\alpha, \beta) = rx + A_k \quad k = 1, 2, \ldots, 9
\]

\( P_k \) in dbm is a signal strength measured at the k-th antenna. \( A_k \) is the k-th antenna gain to the value specified in equation 4.

\[\begin{bmatrix}
G(\alpha - sa, \beta) \\
G(\alpha, \beta) \\
G(\alpha + sa, \beta) \\
G(\alpha - sa, \beta + sb) \\
G(\alpha, \beta + sb) \\
G(\alpha + sa, \beta + sb) \\
G(\alpha - sa, \beta + 2sb) \\
G(\alpha, \beta + 2sb) \\
G(\alpha + sa, \beta + 2sb)
\end{bmatrix}
\]

\[A_k = \]

**C. RSS 9 Antennas**

Using radiation pattern of Figure 2 and equation 1, nine signal strength antennas can be calculated using interpolation equation 4 with the following equation:

\[
P_k(\alpha, \beta) = \sum_{i=0}^{n} \sum_{j=0}^{m} L_{ij}(\alpha, \beta) P_k(\alpha_i, \beta_j)
\]

\[
L_{ij}(\alpha, \beta) = L_i(\alpha_r)L_j(\beta_s)
\]

\[
L_i(\alpha) = \prod_{r=0, r\neq i}^{n} \frac{(\alpha - \alpha_r)}{(\alpha_i - \alpha_r)}
\]

\[
L_j(\beta) = \prod_{s=0, s\neq j}^{m} \frac{(\beta - \beta_s)}{(\beta_i - \beta_s)}
\]

\[
L_{ij}(\alpha_r, \beta_s) = \begin{cases} 1 & i = r, j = s \\ 0 & \text{otherwise} \end{cases}
\]

Where \( n \) and \( m \) is a count of \( \alpha \) and \( \beta \) data. Signal strength of nine antennas can be calculated using equation (2-8).

**D. Estimation of Azimuth and Elevation Angle**

Angle of arrival estimation is based on received signal strength of nine cross Yagi antennas. The highest signal strength received by one antenna indicates that the location of emission source has same direction of the antenna. To determine estimation of azimuth and elevation angles, signal strength of the highest received antenna is compared to its
strength and the vertical ratio, the signal strength of fifth antenna with one of both higher signal strength of fourth or sixth antenna sensed the highest signal strength. To calculate the horizontal ratio and vertical ratio, the vertical ratio (Rb) can be obtained. To retrieve data lookup table in determining horizontal and vertical ratio (Ra). The comparison of red mark with the above or below side is used to determine horizontal ratio. Both horizontal ratio and vertical ratio are used to interpolate to the lookup table in determining the azimuth and elevation angle.

\[ L_1(r) = \prod_{j=0, j \neq i}^{3} \left( \frac{r - r_j}{r_0 - r} \right) \] (13)

First of all the lookup table produced by placing the transmission radio in front of nine Yagi antennas. The antennas rotate in azimuth and elevation direction. In each degree of the nine signal strength, azimuth angle and elevation angle will captured then save it to memory. This file is processed using the above algorithm to obtain the mapping of horizontal ratio and vertical ratio that corresponds to the azimuth and elevation angle.

III. SIMULATION RESULT

A. Radiation Pattern of Nine Antennas

Based on data radiation pattern of cross Yagi-uda antenna obtained by MMANA software, the radiation pattern of nine antennas with configuration like Figure 2 can be shown as Figure 4, which Sa and Sb are 40 degree.

![Radiation Pattern of Nine Antennas](image)

B. Lookup Table

Lookup table is mapping of vertical and horizontal ratio that correspond to the azimuth and elevation degree. To retrieve data lookup table, the nine antennas are rotated towards the left to the right and top to down. For each degree change direction, the nine antennas measure and capture of the nine signal strength data and direction angle (azimuth and elevation). Each data is processed using algorithm that has been described in Chapter 2 to obtain lookup table. By using nine antennas, the lookup table will generate 22 files. Table 1 shows lookup table files.
The rocket contains a radio

Furthermore,

Sudut Azimut

is azimuth ratio and axis y is elevation ration. Both azimuth and elevation ratio have correlated to the azimuth angle (Fig. 5a) and elevation angle (Fig. 5b). The graph describes the content of a lookuptable that is used to estimate the azimuth and elevation angles by interpolation.

<table>
<thead>
<tr>
<th>The Highest Strength</th>
<th>Neighborhood</th>
<th>Ratio</th>
<th>Note</th>
<th>Lookup tabel</th>
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<td>PA1</td>
<td>PA2</td>
<td>Ra</td>
<td></td>
<td>LT1</td>
</tr>
<tr>
<td>PA1</td>
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<td>Rb</td>
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<td>PA2</td>
<td>PA1</td>
<td>Ra</td>
<td>P1&gt;P3</td>
<td>LT3</td>
</tr>
<tr>
<td>PA2</td>
<td>PA3</td>
<td>Ra</td>
<td>P3&gt;P1</td>
<td>LT4</td>
</tr>
<tr>
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</table>

Figure 5 shows lookuptable LT1 and LT2. The axis x is azimuth ratio and axis y is elevation ration. Both azimuth and elevation ratio have correlated to the azimuth angle (Fig. 5a) and elevation angle (Fig. 5b). The graph describes the content of a lookuptable that is used to estimate the azimuth and elevation angles by interpolation.

At the time of measurement, if the first antenna receives highest signal strength, ratio (R) in eq. 10 is interpolated to lookuptable LT1 (Fig. 5a) to derive azimuth angle. To derive the elevation angle ratio (R) is interpolated to lookuptable LT2 (Fig. 5b).

Similarly, when highest signal strength is detected by second antenna, the azimuth angle will be derived by interpolated R value to LT3 (PA1>PA3) or LT4 (PA3>PA1). Elevation angle is derived by interpolation of the R value to lookuptable LT5. Furthermore, when the highest signal strength is detected by antenna 3,4,5,6,7,8,9, the lookuptable used is in accordance with the rules in Table 1.

C. Estimation of rocket direction

To clarify the algorithm in estimating the azimuth and elevation angles that have been developed, the motion of the rocket is simulated. The rocket contains a radio transmitter that continues emitting at 465 MHz frequency. At the receiver, 9 Yagi antennas with 3x3 configuration as shown in Fig. 2 are placed few feet behind the launching pad rocket.

Continuously, the radio signals transmitted from the payload rocket are received by nine cross Yagi-uda antennas. Nine signal strengths are received and processed using the algorithm discussed in Chapter 2 to generate the azimuth and elevation angles.
Figure 8. Rocket trajectory

The signal strength from transmitter which moves can be calculated using equation 2-8. The simulation results of signal strength measurements by nine antennas can be seen in Figure 9. By using equation 10-13, azimuth and elevation angle can be calculated. Figure 9b and Figure 9c shows the estimation results of azimuth and elevation angle of the rocket motion.

Figure 9. Simulation result of azimuth and elevation angle of arrival

Fig. 9 shows estimation of the azimuth and elevation angle. The star red mark indicates the estimation and the circle blue mark indicates the true value. Noise measurements of Figure 10 shows a very small value which proves that this method can be applied to detect location of the source emission radio and estimate the direction of movement of the rocket.
III. CONCLUSION

Estimation of azimuth and elevation angle based on radiation pattern of nine Yagi-uda antennas can be proven to work by simulating and estimating the direction of rocker motion in three dimensions. The algorithm developed in this study uses interpolation of the sum of horizontal ratio square and vertical ratio square into its corresponding lookup table. The horizontal ratio is obtained by comparing the highest signal strength of one antenna to its neighborhood signal strength of right or left side. The vertical is ratio obtained by comparing its signal strength to its neighborhood at above or below its side.

REFERENCES