G403
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 patent 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 elevatioan angle, cross Yagi-Udaantenas, ratio signal strength**

I. INTRODUCTION

Determining azimuth and elevation angle of arrival from source of the radio emission isgreat 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 in the 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

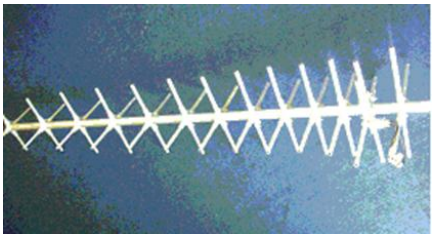
Powerful radio signal that is captured by the receiver of a radio transmitter at a certain point is modeled by Bahl and Padmanabhan [1] with equation (1).

$$P(d)[dbm] = P(do)[dbm] - 10nlog\left(\frac{d}{do}\right) - \begin{cases} nW * WAF & nW < C \\ C * WAF & nW \geq C \end{cases} \quad (1)$$

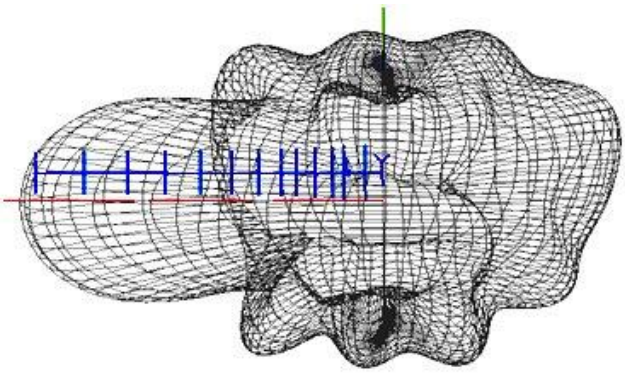
Where n is the path loss by an increase in the distance P (do) is the signal power at the reference distance and d is the distance between the transmitters to the receiver. C is the maximum number of reflections that can infer the magnitude of the received signal strong, nW is the number of reflections 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 antennasthat have a cross-shaped element. Fig. 1 shows the physical appearance of crossYagi antenna and Fig. 1b shows the radiation pattern.



(a) Physical appearance of Cross Yagi-Uda



(b) Radiation pattern of CrosYagi Antenna

Figure 1.Cross YagiUda antenna and radiation pattern

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.

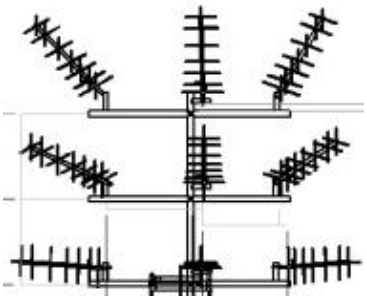


Figure 2. Configuration of nine Yagi-Uda antennas

Fig. 2 shows nine CrossYagi-Uda antennas with different direction angles. Antenna 1th amplifies the signal received (rx) with the gain G(α-sa, β) because the antenna is directed at a different angle then the amplified signal is received in accordance with the received antenna gain angle. Nine antennasassumed 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^o and vertical antennas are arranged with different directions of Sb^o, then signal strength will be received and the equation can be written as follows:

$$rx = St + nW \quad (2)$$

$$P_k(\alpha,\beta) = rx + A_k \qquad k = 1,2,\ldots\ldots 9 \quad (3)$$

Pk in dbm is a signal strength measured at the k-th antenna. Ak is the k-th antenna gain to the value specified in equation 4.

$$A_k = \begin{bmatrix} G(\alpha - sa, \beta) \\ G(\alpha, \beta) \\ G(\alpha + sa, \beta) \\ G(\alpha - sa, \beta + sb) \\ G(\alpha, \beta + Sb) \\ G(\alpha + sa, \beta + sb) \\ G(\alpha - sa, \beta + 2sb) \\ G(\alpha, \beta + 2sb \\ G(\alpha + sa, \beta + 2sb) \end{bmatrix}$$

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:

$$P_k(\alpha,\beta) = \sum_{i=0}^{n}\sum_{j=0}^{m} L_{ij}(\alpha,\beta) P_k(\alpha_i,\beta_j) \quad (4)$$

Pis signal strength measured by antennak-th. The signal strength depends on gain of azimuth (α) and elevation angle (β) of antennas. L_{ij} is polynomiallangrage which can be determined by equation (5) below.

$$L_{ij}(\alpha,\beta) = L_i(\alpha_r) L_j(\beta_s) (6)$$

$$L_i(\alpha) = \prod_{r=0, r\neq i}^{n} \frac{(\alpha - \alpha_r)}{(\alpha_i - \alpha_r)} \quad (7)$$

$$L_j(\beta) = \prod_{s=0, s\neq j}^{m} \frac{(\beta - \beta_s)}{(\beta_i - \beta_s)} \quad (8)$$

$$L_{ij}(\alpha_r,\beta_s) = \begin{cases} 1 & i = r, j = s \\ 0 & otherwise \end{cases} \quad (9)$$

Where n and m is a count of α and β data.Signal Strength of nine antennas can be calculated using equation (2-8).

(2)

D. Estimation of Azimuth and Elevation Angle

Angle of arrival estimation is based on received signal strength of ninecross Yagiantennas. The highest signal strength received by one antenna indicatesthat the location of emission source has same direction of the antenna. To determine estimationof azimuth and elevation angles, signal strength of the highest received antenna is comparedto its

neighborhood signal strength then interpolated to the lookup table.

Figure 3 shows a coverage area of nine antennas. The red mark indicates the maximum signal strength and the blue mark indicates the neighborhood signal strength. The comparison of signal strength of the red mark with blue mark in the left or right side is used to determine horizontal ratio (Ra). The comparison of red mark with the above or below side is used to determin the vertical ratio (Rb). Both horizontal ratio and vertical ratio are used to interpolate to the lookup table in determining the azimuth and elevation angle.

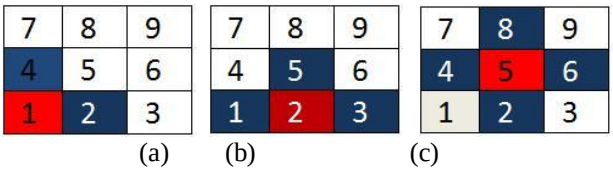


Figure 3.Illustrate coverage area of nine antennas

Figure 3a shows the highest signal sensed by antennas first. To calculate the horizontal ratio (Ra), signal strengthof the first antenna compared to signal strength of second antenna. By comparing the signal strength of first antenna and fourth antenna, the vertical ratio (Rb) can be obtained. Figure 3b show the second antenna sensed a highest signal strength. To calculate the horizontal ratio, signal strength of second antenna compared with one of the both higher signal strength of first or third antenna.Vertical ratio calculated by comparing signal strength of second antenna and fifth antenna. Figure 3c indicated that fifth antenna sensed the highest signal strength. To calculate the vertical ratio, the signal strength of fifth antenna compared to one of both higher signal strength of fourth or sixth antenna.Vertical ratio (Rb) obtained by comparing signal strength of fifth antenna with one of both higher signal strength of second or eighth antenna.

Azimuth and elevation angles are estimated by interpolating the sum of horizontal ratio square and vertical ratio square into lookup table (equ. 11-13). The lookup table is mapping of vertical and horizontal ratio that corresponding to the azimuth and elevation angles.

$$R = {R_\alpha}^2 + {R_\beta}^2 \qquad (10)$$

$$\alpha(r) = \sum_{i=0}^{n} L_i\,(r)a(r_i) \qquad (11)$$

$$\beta(r) = \sum_{i=0}^{n} L_i\,(r)\beta(r_i) \qquad (12)$$

$$L_i(r) = \prod_{j=0;j\neq i}^{3} \left(\frac{r - r_j}{r_0 - r}\right) \qquad (13)$$

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 saveit 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 patent 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.

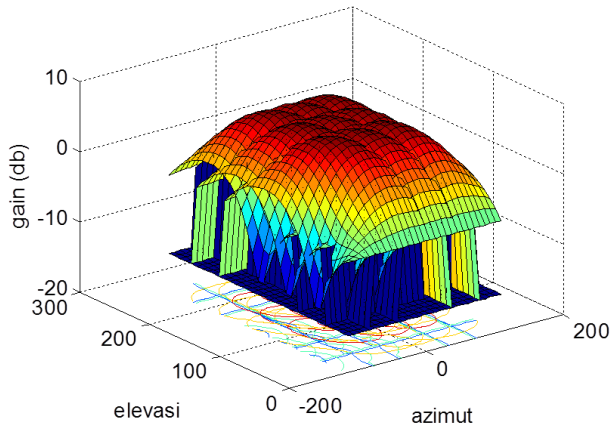


Figure 4.Radiation Paternof Nine Cross Yagi antennas

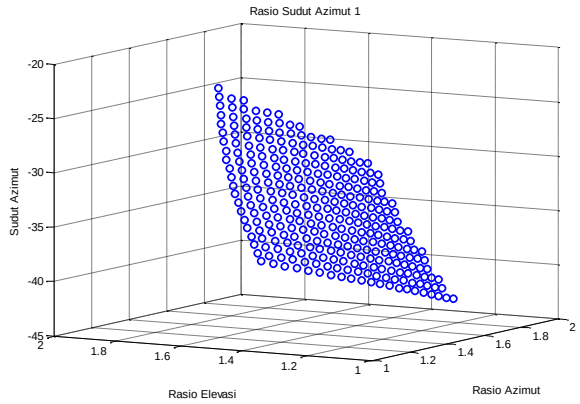
B. LookupTable

Lookup tableis mapping ofvertical and horizontal ratio that correspond to the azimuth and elevation degree. To retrieve data lookup table, the nine antennasare rotated towards the left to the right and top to down. For each degree change direction, the nine antennas measure and capture of the ninesignal 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 tablewill generate 22 files. Table 1 shows lookup table files.

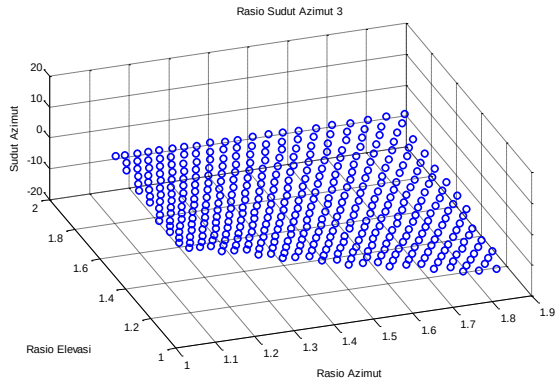
TABEL 1.LOOKUPTABLE DATA

The Highest Strength	Neighborhood	Ratio	Note	Lookup tabel
PA1	PA2	Ra		LT1
PA1	PA4	Rb		LT2
PA2	PA1	Ra	P1>P3	LT3
PA2	PA3	Ra	P3>P1	LT4
PA2	PA5	Rb		LT5
PA3	PA2	Ra		LT6
PA3	PA6	Rb		LT7
PA4	PA5	Ra		LT8
PA4	PA1	Rb	P1>P7	LT9
PA4	PA7	Rb	P7>P1	LT10
PA5	PA4	Ra	P4>P6	LT11
PA5	PA6	Ra	P6>P4	LT12
PA5	PA2	Rb	P2>P8	LT13
PA5	PA8	Rb	P8>P2	LT14
PA6	PA5	Ra		LT15
PA6	PA9	Rb		LT16
PA7	PA8	Ra		LT17
PA7	PA4	Rb		LT18
PA8	PA7	Ra	P7>P9	LT19
PA8	PA9	Ra	P9>P7	LT20
P8	P5	Rb		LT21
P9	P8	Ra		LT22
P9	P6	Rb		LT23

Figure 5.shows lookup tablein 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 lookup table that is used to estimate the azimuth and elevation angles by interpolation.



(a) Azimuth Angle



(b) Elevation Angle

Figure 5. Lookup tablefile LT1 and LT2

At the time of measurement, if the first antenna receives highest signal strength,ratio (R) in eq. 10is interpolated to lookuptable LT1 (Fig. 5a) to derive azimuth angle. To derive the elevation angle ratio (R) is interpolated to lookup table 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 look up table LT5.Furthermore,when the highest signal strength is detected by antenna 3,4,5,6,7,8,9,the lookup tableused isin accordance with the rules in Table 1 .

C. Estimation of rocket direction

To clarifythe algorithm in estimating the azimuth and elevation angles that have beendeveloped, the motion of the rocket is simulated. The rocket contains a radio transmitter that continuesemittingat 465 MHz frequency. At the receiver, 9 Yagi antennas with 3x3 configuration as shown in Fig. 2 areplaced 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 strengthsare received and processed using the algorithm discussed in Chapter 2 to generate the azimuth and elevation angles.

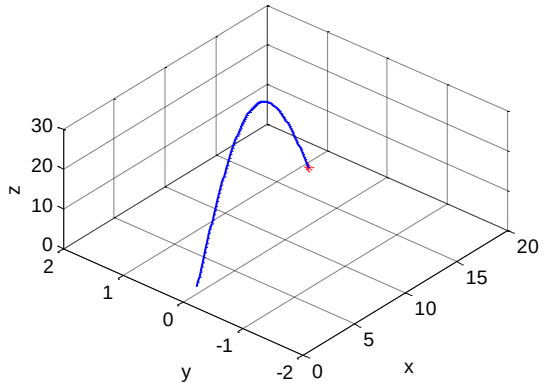
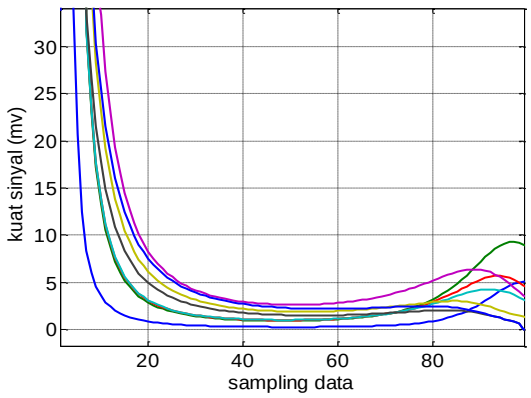
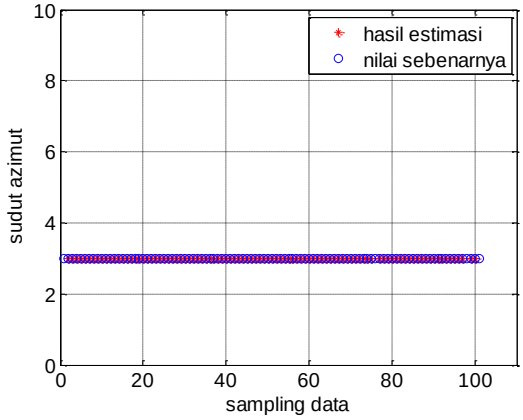


Figure 8. Rocket trajectory

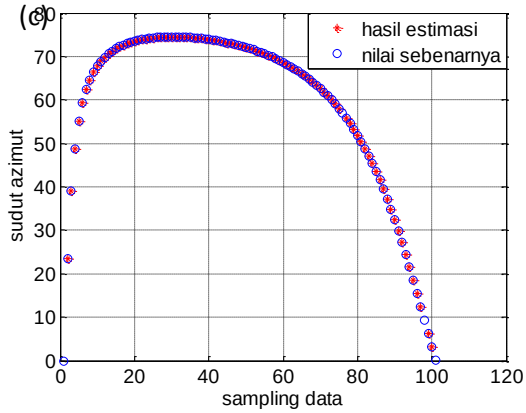
The signal strength from transmitter which moves can be calculated using equation 2-8. The simulation results of signal strength measurements by nine antennas can be seen in Figure 9. By using equation 10-13, azimuth and elevation angle can be calculated. Figure 9b and Figure 9c shows the estimation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



(a) Signal Strength of nine Antennas



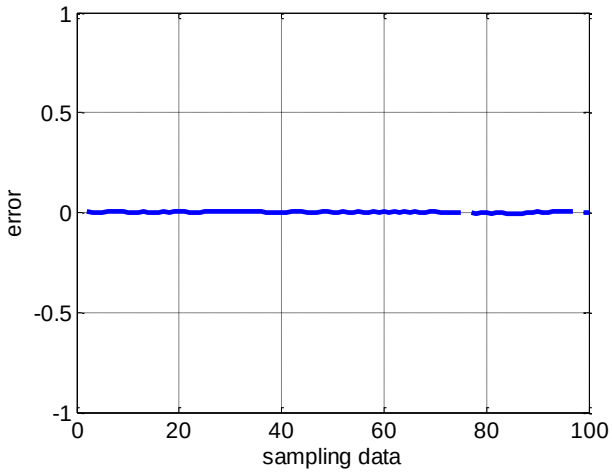
(b) Estimation of azimuth angle



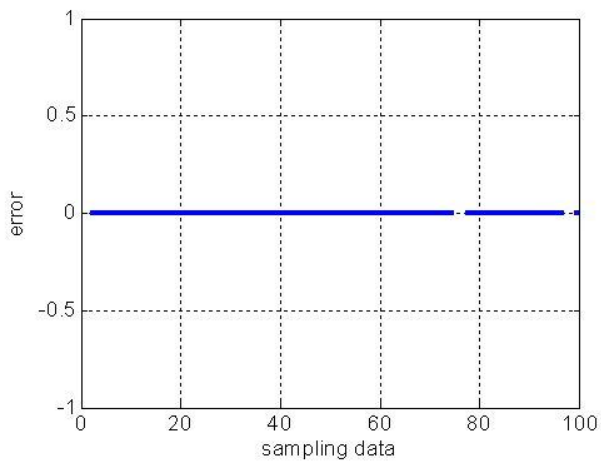
(c) Estimation Elevation angle

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.



(a) Error of azimuth angle



(b) Error Elevation angle

Figure 10.Error of azimuth and elevation angle

III. CONCLUTION

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.

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