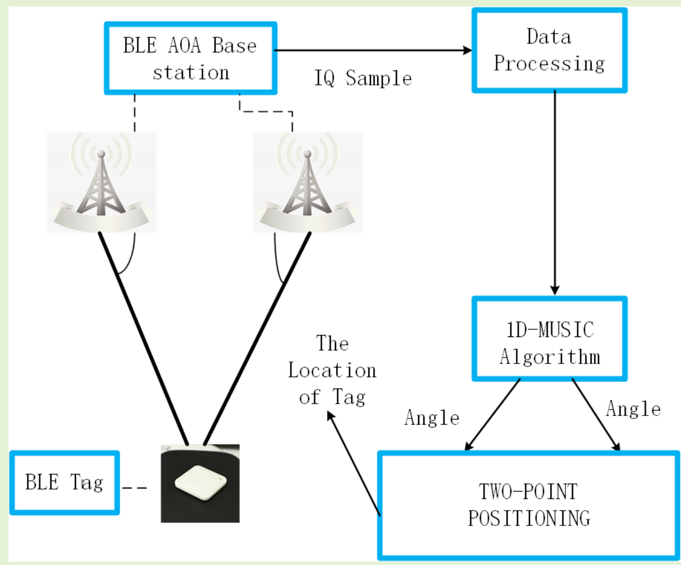
A Indoor Positioning System of Bluetooth AOA Using Uniform Linear Array Based on Two-point Position Principle

Wenzhao Shu, Shuai Wang

***Abstract*— In recent years, indoor positioning research has received a lot of attention, and Bluetooth Low Energy Angle of Arrival(AOA) positioning technology is one of the hot technologies. This paper mainly regards the Bluetooth AOA postiong system as the reasear object and proposes 1D-MUSIC algorithm combining the principle of Two-Point Positioning. This algorithm can not only be applied to linear antenna array, but also to rectangular antenna array and circular antenna array. This methed makes the best of the I/Q data and improves the accuracy of position. By definitions, we take two steps into experiment. First, the IQ samples from Constant Tone Extension (CTE) can be obtained and use the phase difference to get the angle.Then the position of tag can be conclulated by the plane mathematical relations. In this paper, we use a Uniform Linear Array to solve the signal angle, Two-Point Positioning(TPP) is to obtain the angle of two base stations, and uses the spatial mathematical relationship between the two base stations and the label to determine the position of a label. Finally, in order to verify the feasibility of the positioning principle, we conduct experiments in an open room, using three development boards plus array antenna boards to build a complete two-point positioning system. The numerical values of the label positions of different places are collected, and the calculation error is within 0.5m to 1.5m by combining the two-point positioning principle with the Multiple Signal Classification algorithm(MUSIC), and it is proved that the two-point positioning is practically feasible.**



***Index Terms*— Bluetooth low energy, angle of arrival, uniform linear array, IQ sample, MUSIC algorithm, two-point positioning.**

I. Introduction

THE indoor positioning technology can be divided into indoor positioning and outdoor positioning according to the positioning area. Outdoor positioning technology has been developed for many years, and with the continuous advancement of technology, global satellite navigation systems have been widely used in people's lives. GPS is one of the most famous global satellite navigation systems, other well-known foreign navigation systems are Russia's GLONASS, the European Union's GALILEO, China has also developed its own navigation system – BDS [1]. Although outdoor positioning technology has developed so well, most of human life is still mainly indoors, and indoor positioning is in great demand. The indoor positioning environment [2] is very complex, and the walls, the ground and various glasses will block and reflect the signal. Therefore, it is not feasible to apply GNSS directly indoors. Although the indoor environment is complex and diverse, it is closely related to our lives. As a result, [27] [28]indoor positioning technology has also been developed very rapidly. In recent years, various wireless technologies have been applied in indoor positioning, including WIFI, RFID, Zigbee, UWB, BLE, and visible light [3]. Among these positioning technologies, the most interesting development

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is Bluetooth low energy technology. Bluetooth low energy technology is Bluetooth 4.0 version [5] after the only one, its main feature is low power consumption, by using Bluetooth sleep technology to make Bluetooth devices do not work when in hibernation, waiting for work and then wake up, which can greatly reduce energy loss. It is the use of this feature, the general coin cell battery in the state of power supply can make the Bluetooth device work for 3 to 5 years, this technology is very convenient for the application of Bluetooth positioning [4].

Bluetooth uses the ISM's unrestricted 2.4GHZ band, where signals such as WIFI also interfere with it [11]. The Bluetooth channel length is about 80MHZ, according to the protocol, it can be divided into 40 channels, each channel occupies 2MHZ. According to the different channel functions, we can divide it into broadcast channels and data channels, 37 data channels, and 3 broadcast channels. Bluetooth AOA positioning adopts two modes of connection and connectionless [6], the connection mode is to exchange data information using the data channel, in which the data exchange will use frequency hopping technology, which can effectively reduce external interference. Connectionless mode is a direct working broadcast state that provides positioning capabilities for multiple labels.

There are two main principles of Bluetooth positioning, one is to use the Received Signal Strength(RSS) [7], and the other is Direction of Arrival(DOA) [8]. The former is the use of the received signal [23] in space as the path increases, while the signal strength continues to decline. According to this study, previous generations have summarized the mathematical formula of this signal strength model. At the same time, we can also establish a database at different points in the space, and use fingerprint data for data comparison to directly obtain the location information of unknown points in space. DOA is to use different antennas to reach different antennas there will be a phase difference, through the spatial spectrum estimation algorithm [9] to solve the two angles of the signal, one is used to measure the pitch angle of the height, the other is to measure the azimuth angle of the plane [22]. In this article, we use real environment to conduct experiments, use IQ numerical signal processing, and apply one-dimensional music algorithm to truly apply AOA to the actual scene, which is not involved by predecessors. At the same time, we also use two-point positioning to provide a new exploration for building an indoor positioning system.

In order to solve the position of the label, a localization algorithm based on the principle of two-point localization is proposed. Before applying the two-point calculation principle, we firstly use the MUSIC algorithm [10] to solve the azimuth of the tag. Through this, the system of positioning can be made by two process. First, the spatial coordinate system of the respective positions of the tag and the base station is constructed, and it is assumed that the two base stations are just located on the two coordinate axes. Then, according to the trigonometric function, the relationship between the known azimuth and the coordinate is established by using the trigonometric function expression, and the position of the label is calculated by solving the matrix equation at last [12].

The remainder of the paper is organized as follows: After this short introduction, the principle of the BLE AOA is introduced in Section II. Section III details the process of the MUSIC algorithm. Section IV provides the TPP priciple and giving solution expression of position. Section V presents how to deal with IQ data and make position solution. Section VI shows the experiment of using boards to locate the label.Finally, Section VI makes a conclusion through this paper.

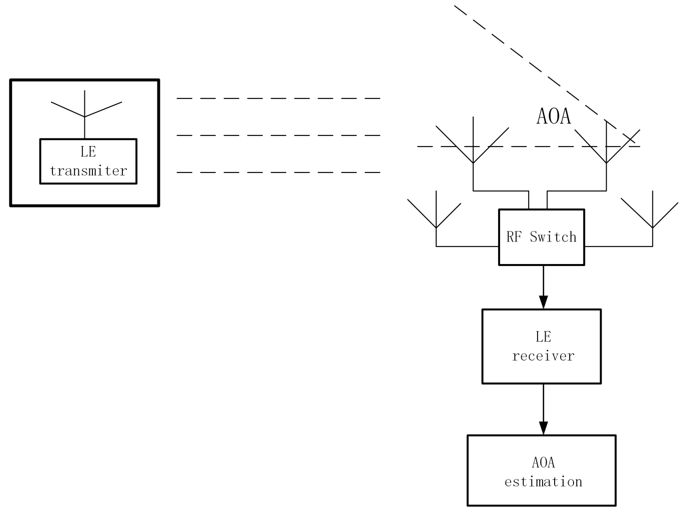


Fig. 1: BLE AOA postioning structure. The transmitter transmits the signal at the same time as the receiver receives samples through the RF switch controlling antenna, and the values sampled by the spatial spectrum algorithm are used to estimate the AOA.

II. AOA PRINCIPLE

Fig.1 represents the Bluetooth AOA system strcture. Bluetooth positioning mainly includes three parts: transmitter and receiver, and antenna array with RF switch.

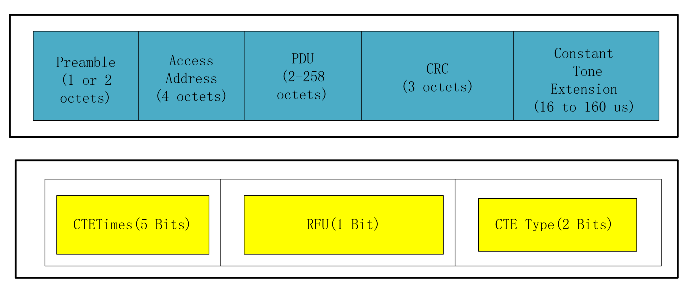


Fig. 2: CTE packet structure. The transmitter transmits the BLE packet including CTE, which is the RF sinusoidal signal in the end of packet. The CTE can be demoulded to IQ samples.

A. CTE and IQ sample

The packet structure of CTE [13] is shown in Fig.2. CTE is short for Constant Tone Extensions, it is a set of extension packets added to the Bluetooth broadcast for Bluetooth direction finding, the length of the packets varies from 16 μs to 160 μs. A CTE is a series of unwhitened all ones. The

CTE package is mainly divided into three parts: the protection period, the reference period and the switch-sample period [14]. The first two period are fixed, the guard period takes 4 microseconds, and the reference period takes 8 microseconds. The length of the switching sampling period completely depends on the length of array antenna, and the sample period can be divided into 1 microsecond and 2 microseconds according to the regulations. The time of the switching period and the sampling period is equal, and the sampling is switched once. For example, assuming that the sampling antenna array is 12 and the sampling period is 1 microsecond, the length of the switching sampling period is 24 microseconds.

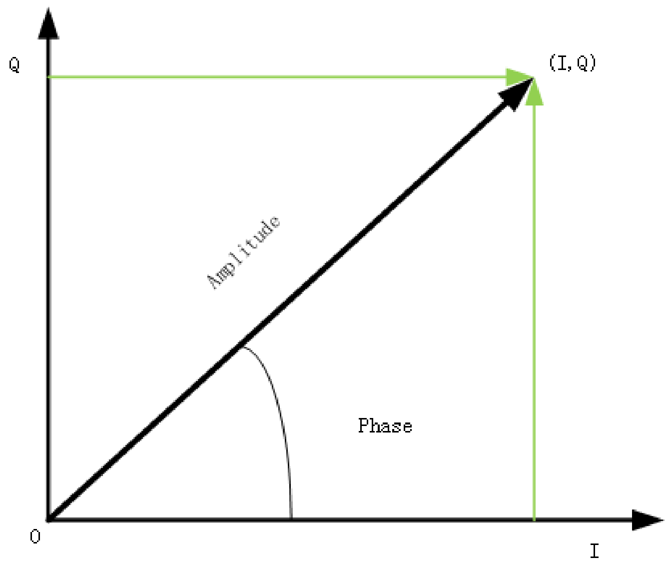


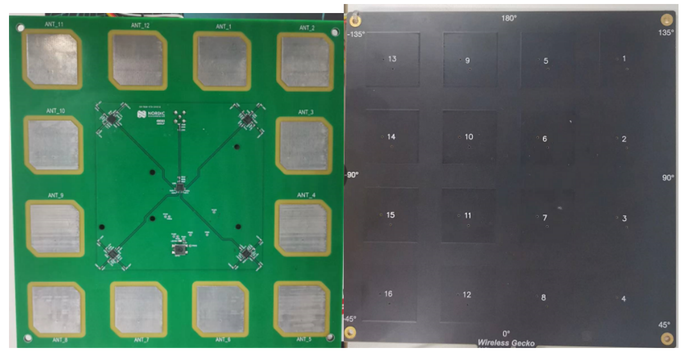
Fig. 3: The relation of original signal and IQ sample. The original signal is devided into In-phase and Quadrature values. The amplitude and phase of signal is can be expressed by I and Q, the phase difference is conculate by two antenna's phase.

CTE can be divided into AOA and AOD according to the type. According to the provisions of Bluetooth protocol 5.1, AOA is selected by default in the configuration, and AOD is generally divided into two types: AOD 1 μs and AOD 2 μs. The CTE is decomposed into I (In-phase) and Q(Quadrature) signals after passing through the antenna array according to Fig.3. Its mathematical relationship can be expressed by the equation 1 and 2 below, the amplitude of the signal is the sum of the squares of the two signals, and the angle is the tangent ratio of the Q-channel signal and the I-channel signal. Assuming that the expression of the signal is $A\sin(\theta)$, and IQ is the value of its two quadrature signals, the following formula can be obtained from the above [13]:

$$A = \sqrt{I^2 + Q^2} \tag{1}$$

$$\theta = \arctan \frac{Q}{I} \tag{2}$$

In the above formulas, A represents the amplitude of the signal, θ represents the phase angle of the signal, whose unit is angle, and I and Q respectively represents the I/Q value of the two signals after sampling.



(a) Nordic antenna array of 12. (b) silab antenna array of 16

Fig. 4: Two types of antenna array. Both antenna arrays have their RF Switch. Through Antenna Parttern, corresponding antenna can be controlled and then sampling the IQ values.

B. Antenna Array

The IQ samples are switched by the antenna array and then divided into two values according to quadrature and in-phase. The antenna array is an array antenna group composed of multiple single antennas. Acoording to the difference of shape, the antenna arrays can be divided into linear array and plane array. A linear array is a set of antennas arranged at equal intervals. Because it is one-dimensional, it is generally used for plane angle estimation calculation. The other is the plane array. The common plane arrays are mainly divided into two types, circular arrays and square arrays. Plane arrays are 2-dimensional and can be used to estimate azimuth and elevation angles. The Fig.4 shows the antenna boards of Nordic and Silab [16], both of which are square array antenna boards. The difference is that Nordic has removed four antennas in the middle, but from the calculation point of view, there is no difference between the two.

The antenna board is controlled by a radio frequency switch, and its logic is a gate circuit in the circuit, which can be combined by 0 and 1 binary to achieve the purpose of controlling multiple antennas. The Fig.4 shows the antenna switching, which is controlled by four IO ports. The four IO ports can control 16 digital states according to different logical combinations. Each digital state corresponds to an antenna switching switch. By Fig.5, the antenna switching control and its lead the logic level of the pin can be displayed.

C. AOA Conculation

AOA Conculation is defided by the priciple of phase difference(PD) [17]. Through, the signal's phase of antena arrary can be conculated. Assuming that the signal is a plane wave and the array antenna is a linear array, since the time it takes to reach different antenna arrays is different, there will be a phase difference between the two adjacent antennas. The specific representation can be seen in the figure below. First, the respective phases of antenna 1 and antenna 2 can be calculated according to the above. The signal reaches antenna 2 at a distance from antenna 1. The distance is calculated according to the electromagnetic wave theory. Then, according to the

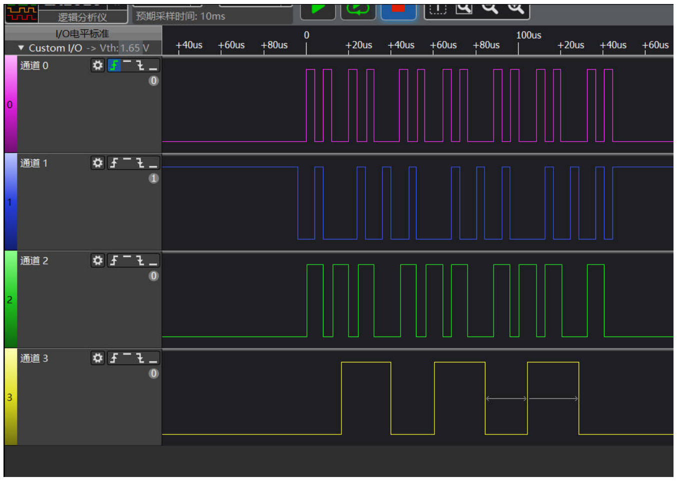


Fig. 5: Logical level of different antennas. The one indicate that the serial number of antenna is used. From bluetooth core 5.1, this RF switch is contrlled by Antenna Parttern.

triangle relationship, the angle and distance can be established by using the sine function [18] to obtain the following formula:

$$D\cos(\theta) = \frac{\varphi\lambda}{2\pi} \tag{3}$$

Finally the above formula is deformed, and the angle value is solved by the inverse cosine function. Available:

$$\theta = \arccos\left(\frac{\varphi\lambda}{2\pi D}\right) \tag{4}$$

Among the founula, θ is the angle of received signal, D is the distance of two antennas, λ represents the wavelength of received signal, φ mean the antennas's phase angle difference.

III. AOA ALGORITHM

In order to explain the AOA algorithm, we put forward the following assumptions:

1. There are generally multiple signal sources, but the signal source (ie, label) used in this paper is regarded as one.

2. The signal is a narrowband signal, and the distance D between the antennas is less than the wavelength of the signal $\frac{\lambda}{2}$.

3. There is no external interference, such as multipath and emission effects caused by objects such as walls and glass. The noise is additive Gaussian white noise.

Fig.6 represents the mathematical model of AOA estimation, where the two angles θ and ϕ represent the pitch angle and the plane angle, respectively. dx and dy represent the spacing between the antennas in the x-axis and y-axis, and the small blue rectangles represent the antennas.

A planar array is a multidimensionalization of a linear array, so we decompose this model into linear arrays in both directions. Since the x-direction and y-direction arrays are similar, only one direction can be analyzed. Assuming that the mathematical expression of the signal is $A\sin(\varphi)$, the actual calculation can be calculated by the IQ value. The type of antenna array is Uniform Rectangle Array(URA) with $M \times N$, M represents the number of array rows on the x-axis,

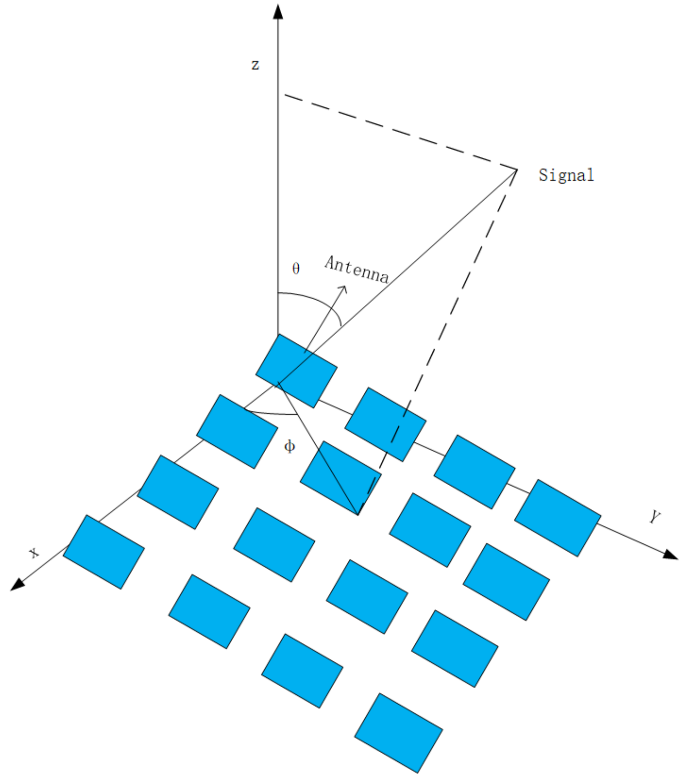


Fig. 6: The model of AOA in URA.The model is made of 16 antennas, it has 4 rows and 4 columns.Every blue rectangle is on behalf of antenna, the antenna is switched and the phase difference can be conclutated.

and N represents the number of columns of array elements on the y-axis. The reference point selects the origin, and the distance of the first antenna [19] on the x-axis relative to the first antenna is $(k-1)dx$. So signal direction vector can be represented by $a_x(\theta,\phi) = e^{(-j2\pi(k-1)dx\sin(\theta)\cos(\phi))}$, Similarly, for y axis, $a_y(\theta,\phi) = e^{(-j2\pi(k-1)dy\sin(\theta)\sin(\phi))}$. Above all, the next formula cab be ratiocinated:

$$a_x(\theta,\phi) = [1,\cdots,e^{(-j2\pi(M-1)dx\sin(\theta)\cos(\phi))}]^T \tag{5}$$

$$a_y(\theta,\phi) = [1,\cdots,e^{(-j2\pi(N-1)dy\sin(\theta)\sin(\phi))}]^T \tag{6}$$

The signal source is one, so the direction matrix of the array element and the direction vector of its array element are equal. Supposing that A_x and A_y are used to denote the orientation matrices in the x-direction and y-direction, respectively. The following formula can be obtained [20]:

$$A_x(\theta,\phi) = [1,\cdots,e^{(-j2\pi(M-1)dx\sin(\theta)\cos(\phi))}]^T \tag{7}$$

$$A_y(\theta,\phi) = [1,\cdots,e^{(-j2\pi(N-1)dy\sin(\theta)\sin(\phi))}]^T \tag{8}$$

For the x-axis subarray, the received signal is:

$$x_x(t) = A_x s(t) + n_x(t) \tag{9}$$

For the y-axis subarray, same as x-axis:

$$x_y(t) = A_y s(t) + n_y(t) \tag{10}$$

The $n_x(t)$ and $n_y(t)$ represent separately the AWGN of x-axis and y-axis.

The whole Output signal $x(t)$ are expressed by $x_x(t)$ and $x_y(t)$, as follow:

$$x(t) = [A_x \odot A_y]s(t) + n(t) \tag{11}$$

Among them, $A_x \odot A_y$ represents the Khatri-Rao product [21] of A_x and A_y. According to the formula, we get: $A_x \odot A_y = A_x \otimes A_y$, the $\otimes$ represents the Kroecker product of two matrix, Calculate the above equation directly:

$$\begin{matrix} A_x \\ \otimes \\ A_y \end{matrix} = \begin{bmatrix} 1, \cdots, e^{(-j2\pi(N-1)dy\sin(\theta)\cos(\phi))}, \cdots \\ e^{(-j2\pi dx\sin(\theta)\sin(\phi))} e^{(-j2\pi(M-1)dx\sin(\theta)\sin(\phi))}, \cdots, \\ e^{(-j2\pi((M-1)dx\sin(\theta)\sin(\phi)+(N-1)dy\sin(\theta)\cos(\phi)))} \end{bmatrix} \tag{12}$$

$A_x \otimes A_y$ is $MN \times 1$ matrix. Through Equation (12), the covariance matrix R_{xx} of the signal can be constructed. According to the spatial spectrum algorithm, the signal subspace and the noise subspace are orthogonal. By decomposing the covariance matrix and sorting according to the size of the eigenvalues, the covariance matrix can be expressed as a signal subspace and the noise subspace.

$$R_{xx} = E[x(t) * x(t)^H] \tag{13}$$

$$R_{xx} = U_S \sum_S U_S + U_N \sum_N U_N \tag{14}$$

Where E means the mean of matrix, H represents the Conjugate transpose of matrix, U_S and U_N indicates separately the signal and noise space eigenvector, $\sum_S$ and $\sum_N$ is on the behalf of separately the signal and noise space eigenvalue.

$$P_{MUSIC} = \frac{1}{A(\theta,\phi)^H U_N U_N^H A(\theta,\phi)} \tag{15}$$

Spectral function is expressed by Equation (15), then using the space search method finds the maximum value of the spectral peak, the corresponding angle value is the direction of the target signal. For linear arrays, only one direction is considered, and the rest of the calculation is the same as the two-dimensional algorithm, so the derivation will not be carried out here.

IV. Two-Poimt Positioning

According to the previous analysis, we can use the AOA algorithm to calculate the angle value. According to the above Fig.7, it is assumed that the angle between the first base station and the tag is θ, and its coordinates in the figure are (x_1, y_1). Similarly, for another base station, its angle with the tag is ϕ, its coordinates are (x_2, y_2)(suppose both angle values are not equal to 90 degree). Since the base station is installed, its coordinates are known. Assuming that the coordinates of the label to be found are (x, y), according to the trigonometric function relationship [24], the expression of its coordinates and the known angle can be established. In order to simplify the calculation, the base station is placed on the y-axis and the x-axis respectively in this experiment.

For base station 1, the relationship can be established according to the tangent value, as follows:

$$tan\theta = \frac{y - y_1}{x - x_1} \tag{16}$$

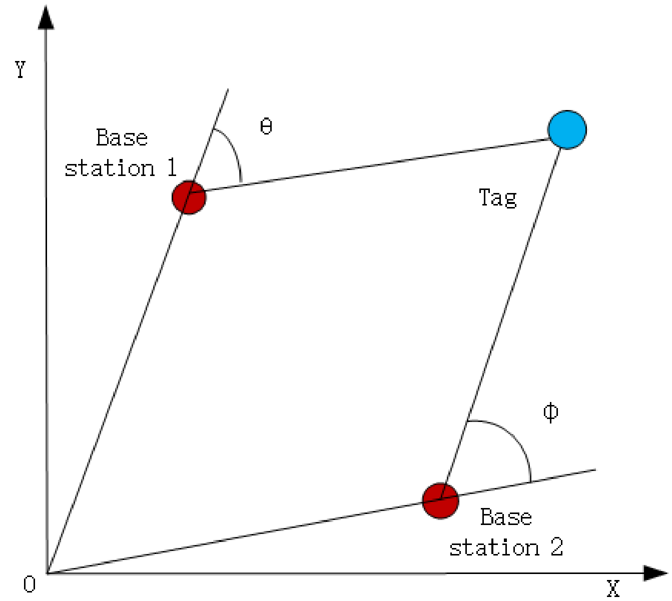


Fig. 7: The construction strpriciple of Two-Point positioning. The two Base stations can get the angles from the same Tag, Then by trigonometric function the tag position can be conculated.

For base station 2, the same expression can be gotten.

$$tan\phi = \frac{y - y_2}{x - x_2} \tag{17}$$

Expand the above formulas, the left side to the coordinate value of the label can be isolated, and the right side is the value of the base station coordinate, which can be written as the following matrix equation:

$$\begin{bmatrix} 1 & -\tan\theta \\ 1 & -\tan\phi \end{bmatrix} \begin{bmatrix} y \\ x \end{bmatrix} = \begin{bmatrix} y_1 - x_1\tan\theta \\ y_2 - x_2\tan\phi \end{bmatrix} \tag{18}$$

Then use the inverse of the matrix, the position of tag can be conculated. The Equation 19 is presentation of tag's position coordinate.

$$\begin{bmatrix} y \\ x \end{bmatrix} = \begin{bmatrix} y_1 - x_1\tan\theta \\ y_2 - x_2\tan\phi \end{bmatrix} \begin{bmatrix} 1 & -\tan\theta \\ 1 & -\tan\phi \end{bmatrix}^{-1} \tag{19}$$

When the base station is not in a special location, it is also possible to establish two equations based on the relationship between the coordinates established by the tag and the base station, using quadrilateral calculations, and then using the mathematical relationship to solve them. The rest will not be elaborated upon.

V. Data Processing and Psition Conculation

This chapter is to use the development board for experiments. The development board we use is the Nrf52833dk development board from Nordic in Fig.8. The antenna board adopts Nordic's rectangular antenna board with 12 antennas. This elaboration is mainly through two aspects of processing [25]. On the one hand, the original acquired IQ value is normalized and digitally processed, and converted into signal

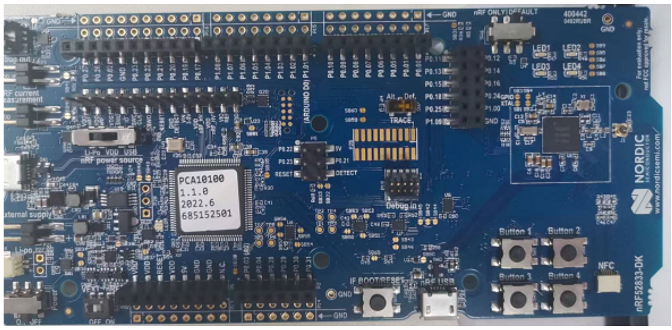


Fig. 8: Nordic nrf52833dk. The board is designed by Nordic company to using Direction Finding, which has strong Tx power and Rx sensibility. There is demo used to get the IQ sample by serial port.

TABLE I: The phase increasing algorithm

The phase increasing algorithm
def function phase-increasing[φ_{ref}]
count = 0;
for i in range(2, len(φ_{ref})):
if φ_{ref}(i) $\leq$ φ_{ref}(i−1):
count += 1
φ_{ref}(i) = φ_{ref}(i−1)+count*2π
else
continue

amplitude and phase. The other is to use the phase to calculate the angle through the one-dimensional MUSIC algorithm, and then use the two-point positioning algorithm [26] to calculate the position.

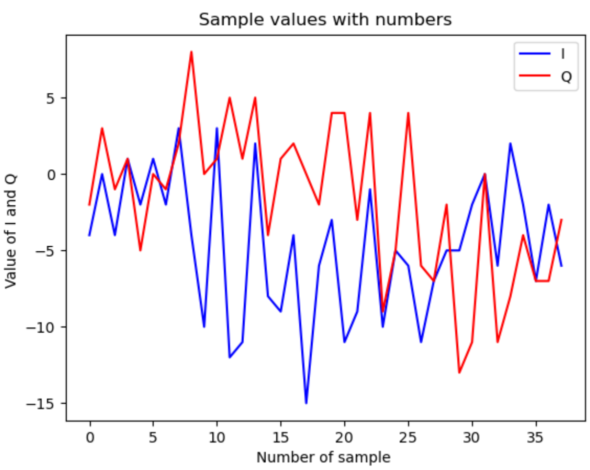


Fig. 9: The original IQ samples. The blue line and red line show the IQ sample from the diffrent antenna, whose values change with antenna switch. The IQ sample are used to conculate the phase and amplitude.

A. Data processing

Based on the two point positioning, we just need to use a linear array. According to the Fig.4, we will use the antennas 11, 12, 1, 2. The antenna 12 is abbreviated as A_{12}, and the others are similar. A_{11} is the reference antenna, A_{12}, A_1, A_2 are all on the sampling antenna and the CTE length is 72 μs. The figure below is the sampled IQ sample, according to the software definition, the cycle period is 60 μs, and the number of sampling cycles is 10 times. As mentioned above, the phase can be calculated with , but due to the angle limitation of the tangent value, when the angle is located in the first quadrant and the third quadrant, the tangent value of the calculated angle is the same, but the angle is different. At the same time, if the value of I is zero, it cannot be calculated directly with the formula, and it is discussed separately at this time. Here Fig.9, according to the relationship between different IQ values and zero, they can be classified, and the derived formula is as follows:

$$\varphi(Q,I) = \begin{cases} \arctan\frac{Q}{I}+\pi & (I<0) \\ \arctan\frac{Q}{I} & (I>0, Q\geq 0) \\ \arctan\frac{Q}{I}+2\pi & (I<0, Q<0) \\ \frac{\pi}{2} & (I=0, Q>0) \\ \frac{3\pi}{2} & (I=0, Q<0) \end{cases} \tag{20}$$

When all IQ value phase values have been calculated, the phase must also be corrected. Since the original signal is a sinusoidal signal, the period is exactly $2\mu s$. The calculated value of the next antenna sampling should be larger than the previous one. For this, we summarize a calculation algorithm [15], as shown in the Table.I. This method is used to process the above data to obtain the final phase difference. According to the above calculation, 38 groups of all phase values that increase according to the specified phase can be obtained. At the same time, the amplitude of the collected signal is calculated.

B. Angle Conclusion and Position Solution

According to the formula, it can be known that the spacing of the antenna elements is very important. Therefore, we use the center of the reference antenna as the origin to establish a coordinate system. According to the antenna technical manual of nordic company, it can be known that the antenna spacing D is 40 mm. It can be known that the x coordinates of the antennas 11, 2, 1, and 2 are 0, 0.04, 0.08, 0.12. At the same time, the obtained phase and amplitude are respectively recorded as $\varphi_1, \cdots, \varphi_{38}$, according to the number, and the amplitude is $Am_1, \cdots, Am_{38}$. The calculation is performed by using the sampling antenna, the first reference antenna samples are culled. Then, the extraction is performed in the same antenna in a loop, and the phase and amplitude vectors are constructed respectively.

$$\varphi_{all} = [\varphi_1, \varphi_2, \cdots, \varphi_{37}, \varphi_{38}] \quad (21)$$

$$Am_{all} = [Am_1, Am_2, \cdots, Am_{37}, Am_{38}] \quad (22)$$

The first antenna sample starts from serial number 9, and the numbers of loop antenna is 3. According to the same antenna data we can get (for example the first antenna):

$$\varphi_{12} = [\varphi_9, \varphi_{12}, \varphi_{15}, \varphi_{18}, \varphi_{21}, \varphi_{24}, \varphi_{27}, \varphi_{30}, \varphi_{33}, \varphi_{36}]^T \quad (23)$$

$$Am_{12} = [\begin{matrix} Am_9, Am_{12}, Am_{15}, Am_{18}, , Am_{21} \\ , Am_{24}, Am_{27}, Am_{30}, Am_{33}, Am_{36} \end{matrix}]^T \quad (24)$$

Using the amplitude and phase obtained above, we construct the signal $s(t) = Ae^{-j*\phi}$. Based on the first antenna, the steering vector of the antenna can be gotten. Assuming that the plane angle is θ, it can be known that its vector is $e^{-j*2\pi 0.04}$. It can be seen that the output matrix of the first antenna is:

$$x_1 = [Am_9 e^{-j\varphi_9} e^{-j0.04\pi}, \cdots, Am_{36} e^{-j\varphi_{36}} e^{-j0.04\pi}]^T \quad (25)$$

$$x = \begin{bmatrix} Am_9 e^{-j\varphi_9} e^{-j0.04\pi}, \cdots, Am_{36} e^{-j\varphi_{36}} e^{-j0.04\pi} \\ Am_{10} e^{-j\varphi_{10}} e^{-j0.08\pi}, \cdots, Am_{37} e^{-j\varphi_{37}} e^{-j0.04\pi} \\ Am_{11} e^{-j\varphi_{11}} e^{-j0.08\pi}, \cdots, Am_{38} e^{-j\varphi_{38}} e^{-j0.04\pi} \end{bmatrix} \quad (26)$$

In the same way, other antennas are processed, and the final output matrix is a 10×3 matrix, which is then averaged, and then singular value decomposition is performed. We go to the noise vector-its last row of covariance matrix. Using the spectral function, we assume that the angle varies from 0 to 180 degrees, and the direction angle can be solved by finding the maximum value using extreme value search.

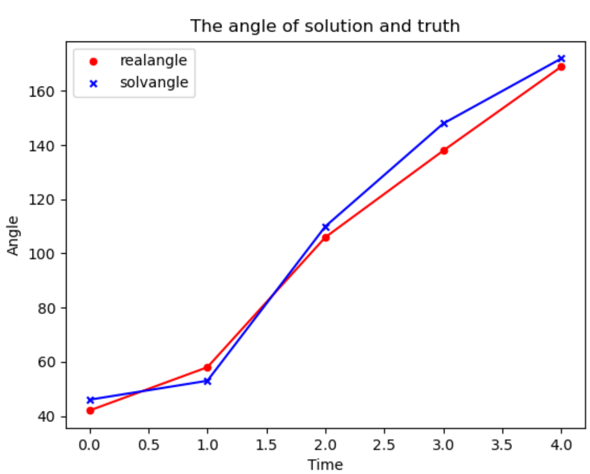


Fig. 10: The angle between the true position and solution by algorithm. The true angle are 42,58,106,138,169 degree, the angle of solution are 46,53,110,148,172 degree. The diffrence is not big.

Here, five positions are selected and their angles are solved using the one-dimensional MUSIC algorithm. The above Fig.10 is its real position angle and the angle solved by the algorithm. It can be seen from the algorithm that the difference between the maximum and minimum angles is between 3 and 10 degrees, indicating that the algorithm can solve the azimuth angle between the tag and the base station, and the accuracy is still very efficient.

Fig. 11: The experiment model. This model are made of two base stations and one tag. The origin is established on the connection between the two base stations, changing the position of tag. The position coordinate can be conculate by TPP.

VI. Experiment Result

As shown in the Fig.11 below, we conducted the experiment in the center of a room with a length of 12 meters and a width of 8 meters. We placed two base stations on the y-axis and the x-axis respectively, with a distance of 0.4 m from the origin. Both base stations have antennas, the ones without antennas are tags. We set the label placement points as (0.52, 0.56), (1.60, 1.90), (2.34.2.69), and then use the implemented algorithm to position the same point, and the solution sampling is 5 times, and the obtained data is averaged. The positions obtained by solving are (0.43, 0.49), (1.29, 1.75), (2.08, 2.79). The obtained data will be converted into the following Fig.12.

From the experiments conducted, the one-dimensional MUSIC algorithm and the two-point positioning algorithm can effectively calculate the position of the label, and the error range, whether in the x-coordinate or the y-coordinate, does not exceed 2 m.

At the same time, due to the accuracy of the one-dimensional MUSIC algorithm calculation, the corresponding angle value is calculated, and then the position of the label can be calculated through two points.

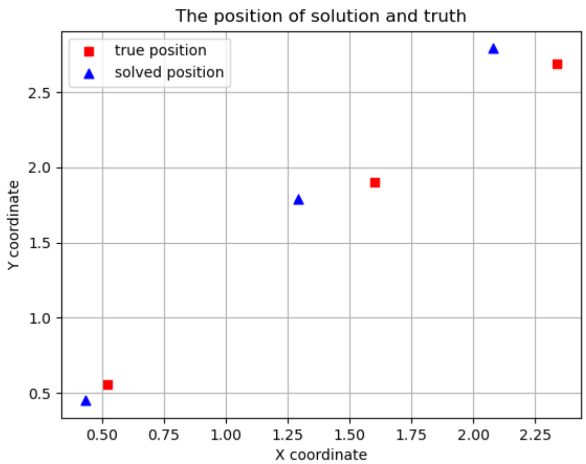


Fig. 12: The position between the true position and solution by TPP. There are 3 group position estimated. The closer the tag is to the base station, the position caculation are more accurate. Even so, the errors are no more than 2 m.

VII. CONCLUSION

As a new indoor positioning technology, Bluetooth AOA has been recognized by the Bluetooth Alliance. Bluetooth AOA positioning technology can achieve high positioning accuracy, low cost and low power consumption. Based on the Bluetooth positioning technology, this article proposes a system for calculating the position of the tag from the improved MUSIC algorithm combined with the principle of two-point positioning. From the experimental results, the use of two-point positioning to solve the tag position is very efficient, and the time required for calculation is very less. Besides this, the most important thing is that its positioning error is also very small, compared with other positioning technologies, so this system is a Bluetooth indoor positioning system worthy of application. First, a principle about AOA is proposed. The structure of the CTE packet, the relationship between IQ sampling and the final signal are introduced in detail, and the amplitude and phase of the calculated signal are explained from the source. Then, we deduce the algorithm flow of MUSIC through the Bluetooth AOA calculation principle, construct the signal from the IQ value, then construct the antenna steering vector and solve the output signal, and finally decompose the eigenvalue of the output signal matrix, and use the spectral function to solve the direction angle.Using two-point positioning to bring in the solved angle, the position coordinates of the label can be solved. The whole system realizes the original DOA estimation from theory to practical application, and the proposed AOA calculation algorithm is very efficient and the calculation accuracy is also very high. In addition, the calculation of indoor positioning can be achieved by using two-point positioning again, which was not available before. The proposed algorithm can effectively solve the position problem of spatial tags. Two-point positioning is very reliable for calculating the plane position, and its accuracy is high and the error is small. In a word, this article is of great reference significance for the application of Bluetooth AOA positioning.

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