IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Date of publication xxxx 00, 0000, date of current version xxxx 00, 0000.

Digital Object Identifier 10.1109/ACCESS.2022.0092316

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

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This work is supported by the Key Scientific Research Platforms and Projects of Guangdong Regular Institutions of Higher Education, China, under Grant 2022KCXTD033; by the Project of Shenzhen Science and Technology Innovation Committee, China, under Grant KCXFZ20201221173202007; by the Scientific Research Capacity Improvement Project of Key Developing Disciplines in Guangdong Province, China, under Grant 2021ZDJS084; by the Guangdong Natural Science Foundation, China, under Grant 2023A1515012103; by the National Key Research and Development Program, China, under Grant 2018YFB1307903; by the Innovation Center of Robotics and Intelligent Equipment, China, under Grant KCYCXPT2017006.(*Shuai Wang and Wenzhao Shu are co-first authors.*)

ABSTRACT In recent years, indoor positioning research has received a lot of attention, and Bluetooth Low Energy Angle of Arrival(AOA) positioning technology is a part of the hot Technical topics. This paper mainly regards the Bluetooth AOA positioning system as the research 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, which makes full use of the I/Q data and improves the accuracy of positioning. We take two steps in the experiment. First, IQ samples from constant tone extension (CTE) can be abtained and are used to calculate the angle. Then the position of the tag can be obtained by the plane mathematical relations. In this paper, we use a Uniform Linear Array to solve AOA, and two-point positioning(TPP) is used to determine the position of a label through the spatial geometric relationships between the two base stations and the label. At last, in check to see 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, in which the absolute error is within **0.3** m to **0.7** m by combining 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(AOA), uniform linear array, IQ sample, two-point positioning.

I. INTRODUCTION

THE 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 the continuous advancement of technology. Global satellite navigation systems has been widely used in people's lives. GPS is part of the most famous global satellite navigation systems, other well-known foreign navigation systems such as Russia's GLONASS, the European Union's GALILEO, and China has also developed its own navigation system – BDS [1]. Although so fast outdoor positioning technology hasing improved, most of human life is still mainly indoors, and indoor positioning is in huge demand. The indoor positioning environment [2] is very complex, in which the walls, the ground and various glass will block and reflect the signal. Therefore, it is not possible to apply GNSS to indoor scene directly. Regardless of the fact that 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, numerous wireless technologies have been applied in indoor positioning, including WIFI, RFID, Zigbee, UWB, BLE [25] [26], and visible light [3], etc. Among these positioning technologies, the most interesting development is Bluetooth low energy technology. Bluetooth low energy technology is appeared after Bluetooth 4.0 [5], and its main feature is low power consumption, by using Bluetooth dormancy to make Bluetooth devices don't work, waiting for work and then waking up, which can greatly reduce energy loss. It is the use of this feature. The general coin cell battery in the state of the power supply can make the Bluetooth device work for 3 to 5 years, so this technology is very convenient for application of Bluetooth positioning [4].

Prior to this, AOA has been thoroughly studied by scholars at home and abroad. Yen [29] et al. proposed the I/Q density-based AOA estimation (IQDAE) algorithm and applied phase difference(PD) filter to improve the accuracy of angle calculation by studying ULA arrays. The Switch Antenna Array (SAA) model was designed and the Nonlinear Least Square (NLS) curve fitting and Gaussian Filter (GF) methods were used to process the IQ values by Zohreh [23] et al,in which the accuracy of the solution is improved by experimental demonstration with TI AOA positioning antennas. In this paper we present a new localisation scheme by using the one-dimensional MUSIC algorithm and applying the TPP principle.

Bluetooth uses the ISM's 2.4 GHz bands, where signals such as WIFI also interfere with it [11]. The Bluetooth bandwidth is about 80 MHz. According to the protocol, bluetooth channel can be split into 40 channels and each channel occupies 2 MHz bandwidth. Depending on the unique channel roles, we can divide it into three broadcast channels and 37 data channels. Bluetooth AOA positioning adopts two modes of connection and connectionless [6]. The connection is to exchange data information using the data channel, in which the data exchange will use frequency hopping technology and can effectively reduce external interference. Connectionless 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 based on tenet that path of the received signal [23] in space increases, while the signal strength continues to decline. Based on this theory, 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 signal to reach different antennas there will be a phase difference, through the spatial spectrum estimation algorithm [9] to solve the two angles. The angles include azimuth and elevation [22]. In this article, we use IQ numerical signal processing, and apply one-dimensional music algorithm to 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 further exploration for building an indoor positioning system.

In order to locate 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] [24] to solve the azimuth of the tag. Through this, the system of positioning can be presented by two process. Firstly, the 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 [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 and provides the TPP priciple and giving solution expression of position. Section IV presents how to deal with IQ data and make position solution. Section V shows the experiment of using boards to locate the label. Finally, Section VI makes a conclusion through this paper.

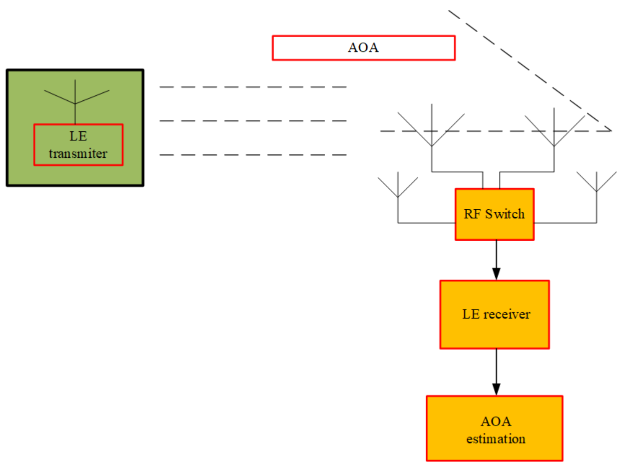

FIGURE 1: **BLE AOA positioning structure. The transmitter transmits the signal at the same time as the receiver receives samples through the RF switch controlling antenna, and the values sampled by the spatial spectrum algorithm are used to estimate the AOA.**

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.

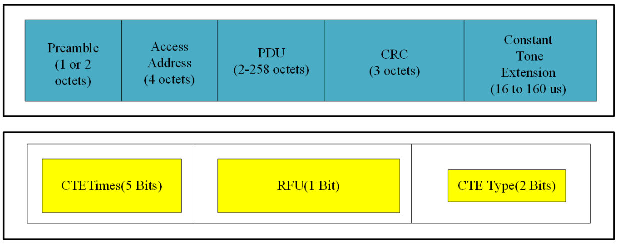

FIGURE 2: **CTE packet structure. The transmitter transmits the BLE packet including CTE, which is the RF sinusoidal signal in the end of packet. The CTE can be demodulated to IQ samples.**

A. CTE AND IQ SAMPLE

The packet structure of CTE [13] is shown in Fig.2. CTE is short for Constant Tone Extensions, and it is a set of extension packets added to the Bluetooth broadcast for Bluetooth direction finding, which the length of the packets varies from 16 μs to 160 μs. A CTE is a series of unwhitened all ones. The CTE is mainly comprised of three parts: the protection period, the reference period and the switch-sample period [14]. The first two periods are fixed, the guard period takes 4 ms, and the reference period takes 8 ms. The length of the switching sampling period completely depends on the length of an antenna array, and the sample period can be subdivided into 1 ms and 2 ms. The time of the switching period and the sampling period is equal, and sampling and switching is held in sequence. For example, assuming that the sampling antennas are 12 and the sampling period is 1 μs, so the length of the switching sampling period is 24 μs.

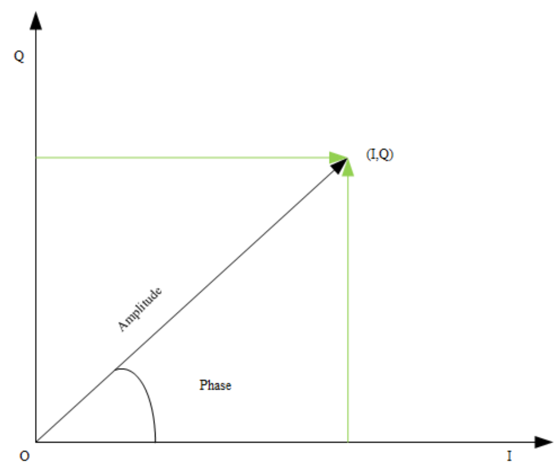

FIGURE 3: **The relation of the original signal and I/Q. The original signal is divided into In-phase and Quadrature values. The amplitude and phase of the signal is can be expressed, and the phase is calculated by I and Q.**

CTE can be divided into AOA and AOD according to the type. According to the provision of Bluetooth protocol 5.1, AOA is on 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) 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, and the phase is the tangent ratio of the Q and the I. Assuming that the expression of the signal is $A\sin(\theta)$, and IQ is the value of its two Orthogonal signals,therefore 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.

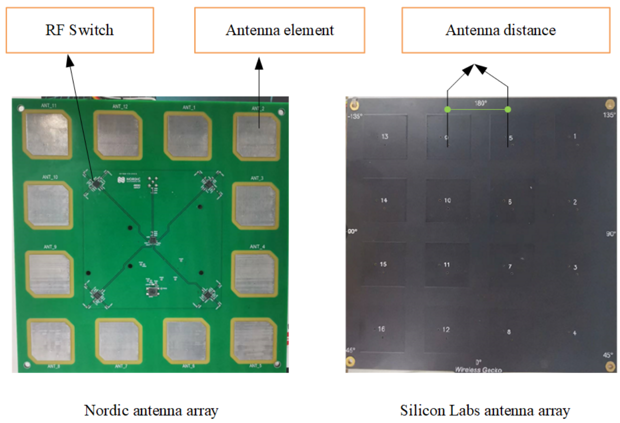

FIGURE 4: **Two types of antenna array. Both antenna arrays have their RF Switch. Through Antenna Parttern, corresponding antenna can be controlled and then sampling the signal.**

B. ANTENNA ARRAY

There are two roles in Bluetooth device connection in BLE 4.0, generally for the master and slave, and after BLE 5.0, it is generally changed to central device and peripheral device.

I/Q datas are sampled by the antenna array. The antenna array is an array antenna group composed of multiple distinct antennas. According to the difference of array shape, the antenna arrays can be divided into linear array and plane array. A linear array is a group of antennas arranged at equal intervals. Because it is one-dimensional, it is commonly used for plane angle estimation calculation. The other is the plane array. Common plane arrays are mainly divided into two types, circular arrays and square arrays. Plane arrays are 2-dimensional and can be utilized to estimate azimuth and elevation. The Fig.4 shows the antenna boards of Nordic and SiliconLabs [16], both of which are square array antenna boards. The difference is that Nordic has removed four antennas in the middle, but from the angle 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, which can be combined by 0 and 1 binary digit to achieve the purpose of controlling multiple antennas. The Fig.4 shows the antenna switching, which is controlled by four GPIOs. Four GPIOs can control 16 digital states according to different logical combinations. Each digital state corresponds to an antenna switching switch and the antenna switching control and its leader the logic level of the pin can be displayed.

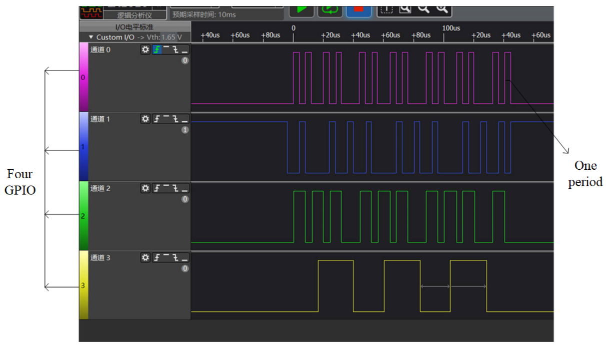

FIGURE 5: **Logical level of different antennas. One indicates the serial number of antenna is used. Of Bluetooth Core 5.1, this RF switch is controlled by Antenna Partern.**

C. AOA CALCULATION

AOA Calculation is defined by the principle of phase difference(PD) [17]. Assuming that the signal is a plane wave and the array antenna is a linear array, since the time it takes in order to reach different antenna elements is different, there will be a phase difference between the two adjacent antennas. The explicit representation can be observed in the Fig.6 below. First, the respective phases of the antenna A and antenna B can be computed according to the Equation (2). There will be a distance difference between the signal reaching antenna A and antenna B. The distance is calculated according to the electromagnetic wave theory. Then, according to the triangular relationship, the angle and distance can be established by using the sine function [18] to obtain the following formula:

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

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

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

Among the founula, θ is the angle of arrival, D is the distance of two adjacent antennas, λ represents the wavelength of received signal, $\Delta\varphi$ means the antennas's phase difference.

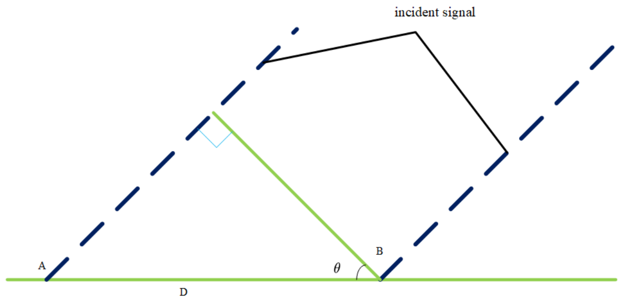

FIGURE 6: **AOA phase difference axiom. Since there is a time delay between the arrival of plane waves at two antennas, AOA can be calculated from the phase difference of adjacent antennas.**

III. AOA ALGORITHM AND TPP THEORY

A. 2-D MUSIC 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, tag) used in this paper is seen 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 not any external interference, such as multipath and emission effects caused by objects such as walls and glass. The noise is additive Gaussian white noise.

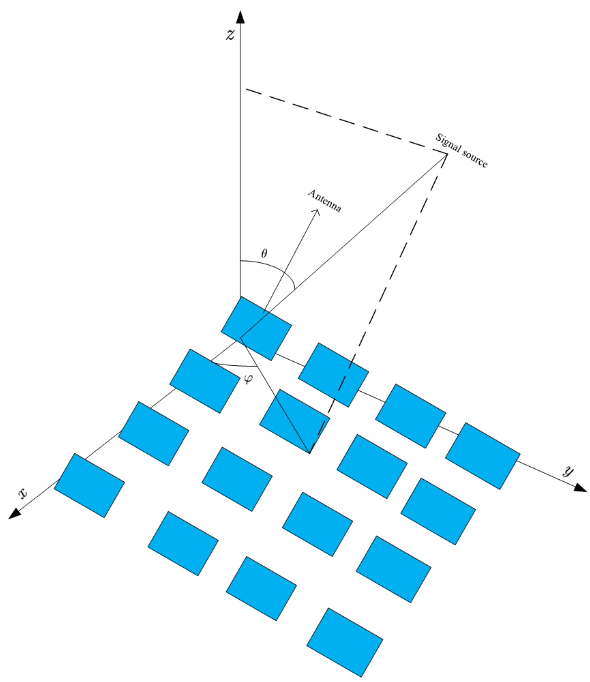

FIGURE 7: **The model of AOA in URA. The model is made of 16 antennas. It has 4 rows and 4 columns and Every blue rectangle is on behalf of antenna.**

Fig.7 represents the mathematical model of AOA estimation, where the two angles θ and ϕ represent elevation and azimuth respectively. dx and dy represent the spacing between the antennas in the x-axis and y-axis, and the distance are same.

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 parallel, only one direction will be analyzed. Assuming that the mathematical expression of the signal is $A\sin(\varphi)$, the actual calculation can be calculated by the I/Q datas. The type of antenna array is Uniform Rectangle Array(URA) of M by N, where M represents the numbers of antenna elements on the x-axis, and N represents the numbers of antenna elements on the y-axis. The reference point selects the reference antenna, hence the distance of the first antenna [19] on the x-axis relative to the first antenna is $(k-1)dx$. As a result antenna transpose 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 can be ratiocinative:

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

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

The incoming signal 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 definition, we get: $A_x \odot A_y = A_x \otimes A_y$, the $\otimes$ represents the Kroecker product of two matrix, calculating 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 to find the spectral peak, and 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.

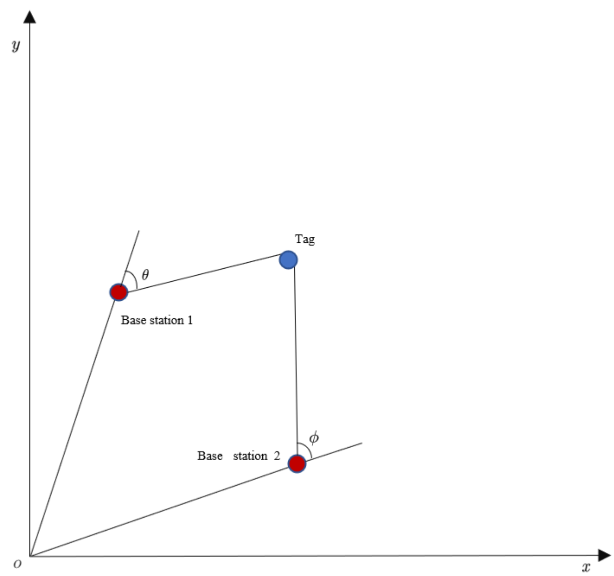

FIGURE 8: **The calculation principle of two-point positioning. The two base stations can get the angles from the same tag, and then by trigonometric function the tag position can be calculated.**

B. TWO-POIMT POSITIONING PRINCIPLE

According to the previous analysis, we can use the AOA algorithm to calculate the angle. According to the above Fig.8, it is assumed that intersection angle between the first base station and the tag is θ, and its coordinates is (x_1, y_1).

Similarly for another base station, its angle is ϕ, its coordinates are (x_2, y_2)(suppose both angle values are not equal to 90°). Since the base station is set up, its coordinates is known. Assuming that the coordinates of the label to be found are (x, y), according to the trigonometric function relationship, and the expression of its coordinates with the known angles can be established. In order to facilitate 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:

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

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

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

Expanding the above equations, the left side of 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 using the inverse of the matrix, the position of the tag can be calculated. The Equation (19) is presentation of tag's position.

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

When the base station is not in a special location, it is also possible to establish two equations based on the relationship between the tag and the base stations, using quadrilateral calculations, and then use the mathematical relationship to solve them. No reasoning will be done here.

IV. DATA PROCESSING AND PSITION CONCULATION

This chapter is used by the development board for experiments. The development board we use is the Nrf52833dk development board from Nordic in Fig.9. The antenna board is equipped with Nordic's rectangular antenna board of 12 antennas. This elaboration is primarily through two aspects of processing. On the one hand, the original acquired IQ value is normalized and digitally processed, and turned into signal 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 to calculate the position.

A. DATA PROCESSING

Based on the two point positioning, we 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 is 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.

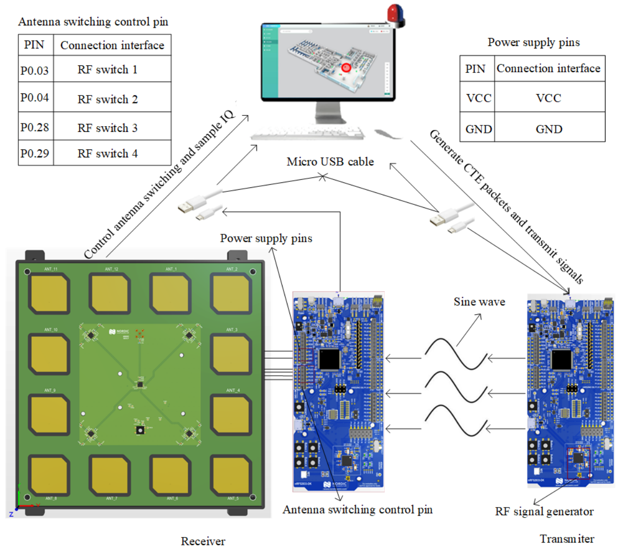

FIGURE 9: **AOA positioning system. The system consists of two Nrf52833 development boards and an array antenna board, and the one with the antenna array is the receiver.**

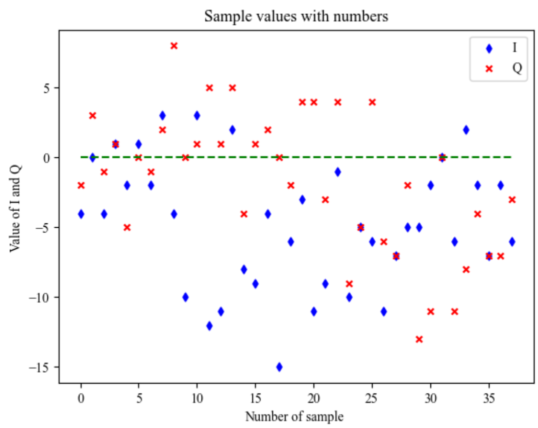

FIGURE 10: **The original IQ samples. The blue line and red line show the IQ sample from the different antenna, whose values change with the antenna switch.**

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 , 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 from the formula, and it is discussed separately at this time. Here Fig.10, according to the relationship between different IQ values and zero, they can be classified, and the derived expression 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 μs. The calculated value of the next antenna sampling should be larger than the previous one. For this, we summarize a calculation algorithm [15], as showed in the Table.1. This method is used to process the above data to obtain the absolute 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

TABLE 1: **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

According to the formula, it can be known that the spacing of the antenna elements is of great importance. 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 recognized 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 φ_1, $\cdots$, φ_{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 is constructed respectively.

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

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

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):

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

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

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:

$$x_1=[Am_9e^{-j\varphi_9}e^{-j0.04\pi},\cdots,Am_{36}e^{-j\varphi_{36}}e^{-j0.08\pi}]^T \tag{25}$$

$$x=\begin{bmatrix}Am_9e^{-j\varphi_9}e^{-j0.08\pi},\cdots,Am_{36}e^{-j\varphi_{36}}e^{-j0.04\pi}\\ Am_{10}e^{-j\varphi_{10}}e^{-j0.16\pi},\cdots,Am_{37}e^{-j\varphi_{37}}e^{-j0.16\pi}\\ Am_{11}e^{-j\varphi_{11}}e^{-j0.24\pi},\cdots,Am_{38}e^{-j\varphi_{38}}e^{-j0.24\pi}\end{bmatrix} \tag{26}$$

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

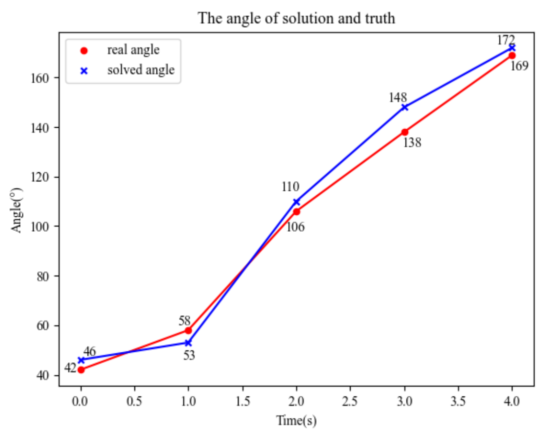

FIGURE 11: **The angle between the true position and solution by algorithm. The true angle are 42°, 58°, 106°, 138°, 169°, and the angle of solution are 46°, 53°, 110°, 148°, 172°. The diffrence is not big.**

Here, five positions are selected and their angles are solved using the one-dimensional MUSIC algorithm. The above Fig.11 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°, indicating that the algorithm can solve the azimuth angle between the tag and the base station, and the accuracy is still very efficient.

V. EXPERIMENT AND ANALYSIS

As showed in the Figure 12 below, we conducted the experiment in the center of a room with a length of 12 m and a width of 8 m. We placed two base stations on the y-axis and the x-axis respectively, with a distance of 0.3 m from the origin. Both base stations have antenna arrays. The ones without antenna array 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, the solution sampling is 5 times, and the obtained data is averaged. The positions achieved by by solving are (0.43, 0.49), (1.29, 1.75), (2.08, 2.79). We can calculate the absolute error of coordinates on the x-axis and y-axis separately, as shown in the Figure 13, the second calculation has a slightly larger error of 0.31 m.

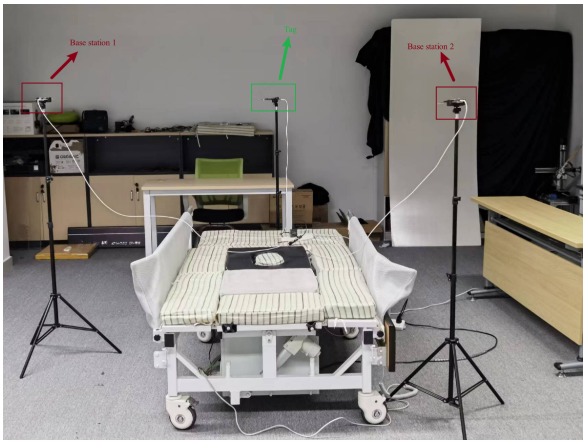

FIGURE 12: **The experimental model. This model is made of two base stations and one tag. The origin is established on the connection between the two base stations, changing the position of the tag. The position coordinates can be calculated by TPP.**

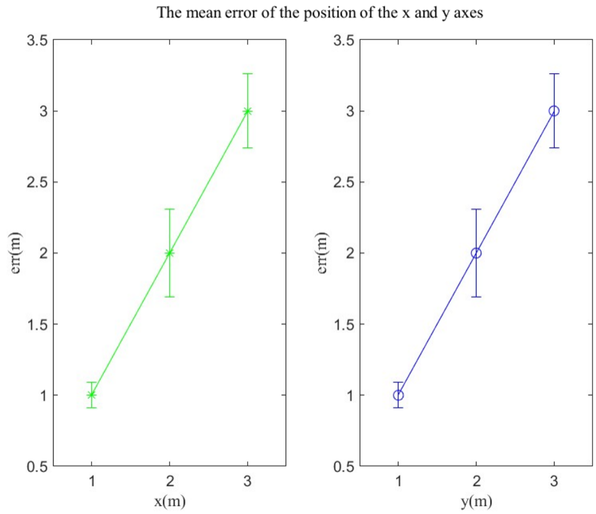

FIGURE 13: **The position between the true position and solution by TPP. There are 3 group positions estimated.The closer the label is to the base station, the more accurate the position calculation. Even so, the errors of the x and y axis are no more than 0.4 m.**

From the experiments conducted, the one-dimensional MUSIC algorithm and the two-point positioning algorithm can effectively calculate the position of the label. About the error range, whether in the x-coordinate or the y-coordinate, varies from 0.09 to 0.31 m.

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

VI. 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 obtaining the position of the tag from the iproved MUSIC algorithm combined with principle of two-point positioning. From the experimental results, using two-point positioning to solve the tag position is very efficient, and the time required for the calculation is very less.

Besides this, the most important thing is that it's 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 is 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 resolved. 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 accessible 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 unimportant. In a word, this article is of major reference significance for the application of Bluetooth AOA positioning.

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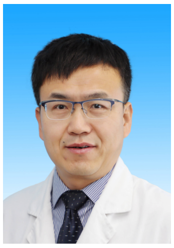

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