An effectual direct position determination approach for enhancing the accuracy of the indoor positioning system

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ABSTRACT

In this paper, an efficient direct position determination approach, which is based on the combination model using the Kalman filter, has been proposed. The proposed approach enables accurately estimating the emitter position in various scenarios. Two scenarios have been created to evaluate the performance of the approach in the case exist line of sight (LOS) paths and do not exist a line of sight paths (NLOS) on the way movement of the emitter in the indoor environment. The simulation outcomes show that the proposed approach achieves more accuracy compared to angle-of-arrival (AOA), Direct Position Determination (DPD), and Direct Source Localization (DiSouL) techniques in the same scenario. In particular, when the probability of errors was less than 1m and the environment has not existed with LOS paths, the proposed approach has achieved accuracy is about 60% compared to 1%, 35%, and 45% of AOA, DiSoul, and DPD, respectively.

Keywords: Indoor positioning system; Direct Position determination; Kalman filter.

1. INTRODUCTION

In recent years, improving the accuracy of indoor positioning is an issue that attracts attention from researchers due to indoor location-based services tend to grow and require more accuracy. Position determination in wireless communication may enable many applications such as emergency services, autonomous driving, elder assistance, finding a way, and geographic routing,... The indirect localization to estimate the emitter position is executed by a two-step procedure. In the first stage, the direction of the angle, arrival time, the difference in time, or the difference in frequency are collected, and then the emitter position is determined by using the formerly assessed parameters in the second stage [6–8]. Some of the famous indirect localization methods often use such as Directions of Arrival (DOA) [1-2, 18], Time of Arrival (TOA) [9], Time Difference of Arrival (TDOA) [3, 16], and Frequency Difference of Arrival (FDOA) [3], these two-step methods are inefficient when the environment does not exist a line of sight (LOS). A novel localization approach has been introduced as Direct Positioning Determination (DPD) in [5-7, 8, 10-13], and [21]. These studies showed that the accuracy of DPD archives the superior efficiency compare to the two-step method especially when the Signal to Noise Ratio (SNR) is low. Additionally, DPD has capable of locating more emitters than the number of sensors at each base station [5]. Another direct position determination method is called DiSouL which has been introduced in [6]. This approach is based on the superiority of massive arrays that is a high angular resolution which was the reason DiSouL can be determined the position of the object directly from the AOAs of the LOS path even when the signal-to-noise rate was very low. In [11-12], noncircular signals have been considered in DPD. In those papers, the authors have derived the property of completely non-circular signals in the frequency domain. The received signal partition algorithm has been introduced in [13]. This algorithm is based on dividing the received signal into multiple non-overlapping short-time signal intervals, after that, uses the TDOA, the

FDOA, and the fusion among the short-time signals to determine the location of the emitter. In [16], the method that presented the aptitude to position multiple emitters synchronously has been introduced. It is appropriate for military and national security applications, which are not interested in the cost. However, the DPD method required a more stringent transmission of the received signals than AOA and TOA. Instead of simply requiring the transmission of measured parameters such as angle parameters, transfer times, and time differences, DPD requires the transmission of the received signals (possibly sampled) to the central processing location. Many papers have used DPD as a method to estimate the location of the emitter [5-8, 10-14]. However, most of these methods assumed the environment always has LOS paths or pure LOS paths. In an indoor environment with dense multipath signals and obstacles, DPD may not be able to estimate the emitter location. We proposed an approach that combined DPD with a Kalman filter to improve the accuracy of estimation of the emitter in the case the LOS path did not exist. The simulation results in the same scenario show the superior efficiency of the proposed approach compared to traditional AOA [4], DPD [5], and DiSouL [6].

In the paper, the rest of it is organized as follows. In section 2, we present the problem formulation that we used. The system model and proposal algorithm are introduced and analyzed in section 3. In section 4, we present numerical results that demonstrate the performance of the proposed approach, and we introduced our conclusions in section 5.

2. PROBLEM FORMULATION

2.1. The principle of Direct Positioning Determination

In this section, we presented the base principle of DPD. To do this, we considered a scenario in the two-dimensional space, one emitter and the number of base stations (BS) were L [6]. The assumption the location of BSs has known. L base stations fixed with arrays of S_l antenna each. Assume that the emitter position is located at coordinate and the center of gravity of the stations' arrays is determined by the vector of coordinates. At the l-th base station array, the received signal is represented in Equation (1):

$$\begin{gathered} r_l(t) = r_l^{LOS}(t) + r_l^{NLOS}(t) + n_l(t) \\ 0 \le t < T_{obs} \end{gathered} \tag{1}$$

In which,

$$r_l^{LOS}(t) = b_l a_l(\theta_l(p)) s(t - \tau_l(p)) \tag{2}$$

$$r_l^{NLOS}(t) = \sum_{m=1}^{P_l} b_l^m a_l(\theta_l^m) s(t - \tau_l^m) \tag{3}$$

Where $r_l(t)$ is a vector $(M \times 1)$ elements and it is a time-dependent vector. The channel effect (attenuation) is represented by b_l that is an unknown complex scalar, a_l is the array response vector at base station l. B_l is the channel attenuation between the p-th transmitter and the l-th base station. T_{obs} is the observation time. $n_l(t)$ is white Gaussian noise, θ_l and τ_l are the angle of arrival (AOA) and time of arrival (TOA). (1) is the sum of the two components. The first component (2) is the received signals, which are relative to the LOS path and the second component (3) is the obtained signals in case of the absence LOS path. The parameters $\{b_l\}, \{b_l^m\}, \theta_l^m, \tau_l^m$ are respectively the values of the channel gain, AOA and TOA of the m-th NLOS path component for the NLOS path. All of the parameters are unknown and at each array l the amplitudes $\{b_l\}, \{b_l^m\}$ do not change across antennas. The source position is related to the LOS path parameters following equation (4), (5):

$$\tau_l(p) = \frac{\|p - \tilde{p}_l\|}{c} \tag{4}$$

$$\theta_l(p) = \arctan\left(\frac{p^y - \tilde{p}_l^y}{p^x - \tilde{p}_l^x}\right) + \pi.1(p^x < \tilde{p}_l^x), \tag{5}$$

In which the speed of light is defined c and the arctangent function has range in $\left[-\pi/2 : \pi/2\right]$, 1(P) is the logical expression that equal 1 if P is true.

The emitter position problem has been solved by the way that we used a uniform grid of Q positions and M_l angles for each base station array. It can be express in the Equation (6), (7), respectively.

$$L = \left\{\pi_1, \ldots\ldots, \pi_Q\right\} \subset R \cap F, \tag{6}$$

$$A_l = \left\{a_1, \ldots\ldots, a_{M_l}\right\} \subset \left[0, 2\pi\right) \tag{7}$$

We assume that the position of the emitter is to lie on a grid position and the AOAs of the NLOS paths are also in the grid of angles [6]. Consider a matrix $X \in \mathbb{C}^{Q\times L}$, X is the matrix whose entry on row q and column l. The components of this matrix are x_{ql}. X is the complex gain of a LOS path from grid position π_Q to base station.

Let the complex gain of NLOS paths that arrives at the $l-th$ base station with angle a_m is a y_{ml}. X is a matrix whose rows equal zero excluding one row, $y_{ml} = 0$ when angle a_m is not equal to the arrived angles of the NLOS path and $y_{ml} \neq 0$ in the other case. We have $\|y_l\|_1 = \sum_{m=1}^{M_l} |y_{ml}|$ and $y_l = \left[y_{1l}, \ldots, y_{M_l l}\right]^T$. X, y_l can be determined following (8-9)

$$\|X\|_{2,1} = \sum_{q=1}^{Q} \sqrt{\sum_{l=1}^{L} |x_{ql}|^2} \tag{8}$$

$$\|y_l\|_1 = \sum_{m=1}^{M_l} |y_{ml}| \tag{9}$$

where $y_l = \left[y_{1l}, \ldots, y_{M_l l}\right]^T$

Following [6], by applying a matched filter at the sampling time, the received after discrete Fourier (10)

$$\bar{z}_l = z_l^{MF}(t_l) = \bar{b}_l a_l(\theta_l(\mathrm{p})) + \sum_{m=1}^{P_l} b_l^{-m} a_l(\theta_l^m) + \bar{n}_l \tag{10}$$

In which $\bar{b}_l = r_s(t_l - \tau_l(p))b_l$,$b_l^{-m} = r_s(t_l - \tau_l^m)b_l^m$, $\bar{n}_l$ is the noise. We determined p from $\left\{\bar{z}_l\right\}_{l=1}^{L}$ by the way that was to determine the sampling times and the estimated TOA. To reduce the complexity of estimating emitter position, the tools that have been used are compressive sensing and the uniform grids. Those grids are the emitter's position on the survey plane [6]. Those grids have presented in (11)

$$L = \left\{\pi_1, \ldots\ldots, \pi_Q\right\} \subset \Re \cap F \tag{11}$$

and likewise for the arrive angles, there will be grids of angles for each base station array (12)

$$A_l = \left\{\upsilon_1, \ldots\ldots, \upsilon_{M_l}\right\} \subset \left[0, 2\pi\right). \tag{12}$$

The position of the emitter has been estimated following (13) [6].

$$\hat{p} = \arg\max_{\pi \in Lo} \sum_{l=1}^{L} \frac{\left| a_l^H(\theta_l(\pi))\,\overline{z}_l \right|^2}{\left\| a_l(\theta_l(\pi)) \right\|_2^2} \tag{13}$$

2.2. Kalman filter

The Kalman filter has used to estimates the state of a discrete-time controlled process. The linear stochastic equation describes the relationship between the parameters is presented in (14)

$$x_{k+1} = F_k x_k + G_k u_k + \omega_k \tag{14}$$

In which x_k is state at time k, u_k is a input control vector, ω_k is the process noise vector – normally it is the AWGN, F_k is a $n \times n$ dimensional matrix that is the transfer matrix of the system. Note that in practice this matrix can be changed with each time step, but here we assumed it is constant. G_k is the matrix that relates the optional control input u to the state x.

Our proposed model uses a Kalman filter with the following assumptions [19-20]:

- The change of state follows a linear motion model in 2-dimensional space assuming constant motion velocity.
- The transition matrix is represented by (15):

$$F_k = \begin{bmatrix} 1 & 0.1 \\ 0 & 1 \end{bmatrix} \tag{15}$$

- The input conversion matrix is represented by (16):

$$G_k = \left[x\ 0.2\ y\ \ 0.1 \right]^T \tag{16}$$

- The control input vector u_k is described by (17):

$$u_k = \left[x \quad 0 \quad y \quad 0 \right] \tag{17}$$

Whereas x, y in (16) and (17) are coordinates measured by DPD algorithm. Furthermore, assuming that the possibility of observing the state is represented by a linear equation according to (18):

$$z_k = H_k x_k + v_k \tag{18}$$

In the equation (18), z_k is the observed or measured information at time k, x_k is the state at time k, H_k is observation matrix that is the $m \times n$ - dimensional matrix, and v_k is the observation noise vector.

In practice H_k matrix can be changed with each time step or measurement, we assumed it is constant in this paper. The measurement matrix H_k can be expressed as H_k = transpose (H_1), in which H_1 can be expressed as (19):

$$H_1 = \begin{bmatrix} x_1 \\ y_1 \end{bmatrix} \tag{19}$$

In this paper, we have chosen x_1 = [0: 0.1: 1] and y_1 = [$x_1^{1.8}$].

3. THE PROPOSAL ALGORITHM

3.1. System block diagram

The principle of direct position determination is a method that the location of the emitter is estimated one step. In which, the collected data processed directly without processing parameters such as the angle of arrival, time to arrival, or time difference of arrival. Therefore, it is imperative that the DPD method work effectively is that the signal transmission environment must exist a LOS path to ensure the source location can be estimated [5-6]. Although relying on the high angular resolution of the Massive MIMO system and using many techniques to separate the LOS path from the NLOS path. However, in some scenarios the LOS path was blocked, DPD cannot be able to estimate the emitter location. In response to these challenges, we propose a solution using a Kalman filter in combination with DPD to estimate the emitter position. With the ability to predict the position based on the parameters at a previous time, using the Kalman filter in combination with the DPD could estimate the next position of the emitter without depending entirely on the received signal at the online time. Therefore, in the absence of the LOS path at the time of estimation, using this solution, the emitter location can be completely reliable.

Fig. 1 depicts the proposed algorithm block diagram. In this diagram, signals are received from the data acquisition unit and then the position of the emitter has been estimated using the DPD direct positioning method. This data is fed into the filter block, the filter factors of the Kalman filter have been put on to the system and it used these factors to estimate the emitter's position. After the emitter position has been obtained, these values are used to correct the results for subsequent estimation. The values that represent the location of the emitter through the filter block do not depend entirely on the value obtained at the time of estimation using DPD but also depend on the estimated value at earlier times of the Kalman filter. Due to this, the source position can be estimated even in the absence of the LOS path.

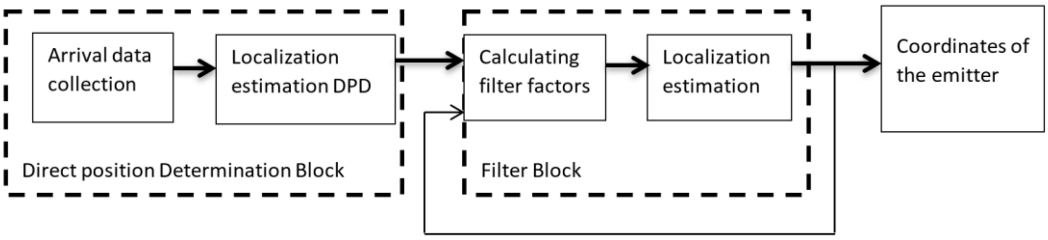

Figure 1. *The proposed system block diagram.*

3.2. The proposed algorithm

The proposed algorithm has been introduced in this section [6]. The algorithm to estimate the location of the emitter was presented by Algorithm 1 below:

```
Proposed algorithm
Initialize $\hat{L} = L$ and assume $\hat{p} = \varnothing$
Set threshold $\varepsilon$ according to [6],[17]
If $\sum_{l=1}^{L} \left\| \bar{z}_l \right\|_2^2 > \varepsilon$ then
  While $\hat{p} = \varnothing$ and $\hat{L} > 1$ do.
    Set $\omega = \sqrt{\hat{L} - 0.5}$
    Determine X and $y_l, \forall l$
    If $X \equiv 0$ then set $\hat{L} \leftarrow \hat{L} - 1$
    else
            $\hat{q} = \arg\max_q \left\| X_{q,:} \right\|_2$
      estimate $\hat{p} = \pi_{\hat{q}}$
    end if
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  end while
else
Estimate $\hat{p}$ by (13) to obtain $(\tilde{x}_{DPD}, \tilde{y}_{DPD})$
Calculating filter factors using (14), (15), (16), (17).
Estimate $\hat{p}$ combination DPD and Kalman using (18).
End if.
```

The algorithm 1. *The pseudo-code to estimate the location of emitter.*

4. NUMERICAL AND RESULTS

In this section, we have built two scenarios to estimate the location of the emitter using other approaches.

Case 1: The emitter moves indoor environment at a maximum speed of 1.38 m/s, the trajectory of the emitter moves on a random curvature curve, and our assumption the environment always exist a LOS path.

Case 2: The emitter moves indoor environment at the same speed of 1.38 m/s, the trajectory of the emitter moves on a random curvature curve and there has not existed LOS path.

To evaluate the effectiveness of the proposal approach, we have used the same scenarios for the approaches. Specifically, we compare performance of the proposal approach to the traditional AOA approach, DPD and DiSoul approaches.

(1) Estimation of the emitter location using AOA method;

(2) Estimation using DPD method according to the problem which is presented in section A;

(3) Estimation of the emitter location using DiSoul method [6];

(4) Estimation of the emitter location using combination DPD and Kalman filter based on the ability to predict the state of the Kalman filter.

We have evaluated the performance of the system based on RMS error as follows:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(P_i - P_i\right)^2} \tag{20}$$

Where P_i is the emitter position, and P_i is *i*-th estimation position, and *N* is the total number of survey points.

Test case 1:

We used the simulation parameters according to [6]. The emitter is located randomly on an area of size 100m x 100m. The coordinates of four base stations are [45 m, 45 m], [45 m, -45 m], [-45 m, 45 m] and [-45 m, -45 m]. The main assumptions here are that the emitter moves at a speed of 1,38 m/s, and the initial grid resolutions are gres = 5 m, and ares = 5.710 (detail in [6]). The fact proves that the lack of angular resolution is not the main cause of AOA estimation errors. The main errors are normally by peak ambiguities. Previous studies have shown that the main cause of positioning errors is that in the indoor environment where there are many obstacles, the signal is attenuated and the LOS path does not exist. To ensure generality, in this scenario, we have used four base stations (BS) and in which each BS is equipped with a 70-antenna uniform circular array (UCA) [18] whose radius is 24 cm. We have chosen UCAs with this radius because it makes the inter antenna spacing equal to half wavelength. Otherwise, contrary to ULAs, UCAs have equal angular resolution towards all directions on the plane. We have chosen four BSs because it makes positioning a bit more robust to multipath than using only three base stations as in [5].

Figure 2 illustrated the displacement trajectory of the emitter which is graphically represented in the case 1. It consists of five curves of blue, green, red, black and yellow representing the trajectory of the real position, the estimated trajectory of the DPD algorithm, combination DPD and Kalman, DeSoul and AOA approach, respectively. The simulation result shows that the red curve closely follows the blue curve and the yellow and green curves have a significant deviation from the real trajectory.

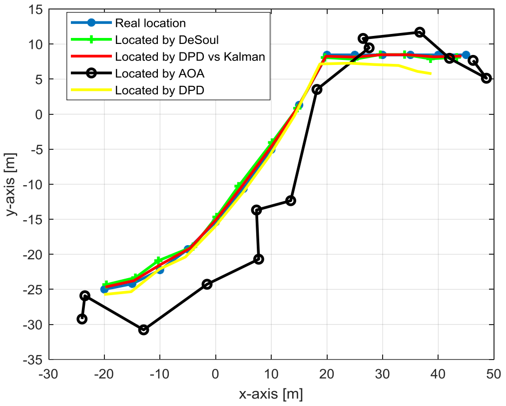

Figure 2. *The displacement trajectory of the emitter in case 1.*

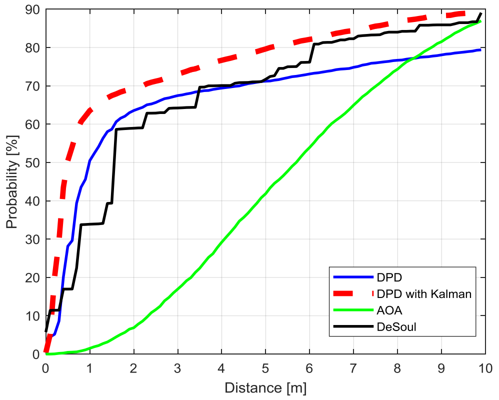

Figure 3. *The RMS error probability between the proposal approach to the others in case 1.*

Looking at the values of the points after the estimate, we can see that the proposed method's accuracy is superior to other methods.

If the emitter moves according to a smooth curve orbit, the estimated error of AOA, DPD, and DiSoul methods compared to the real position is relatively good. However, in the case where the emitter has a sudden shift such as here is at coordinate (8.46, 20), the proposed approach achieves superior accuracy demonstrated in figure 3. This figure illustrates the accuracy position probability of the proposed approach compares to other approaches. The dashed curve describes the probability of error of the proposed method when estimating the emitter position in case 1. It is clear that, with an error of less than 1 m, the proposed method improves efficiency significantly compared to other methods.

Test case 2:

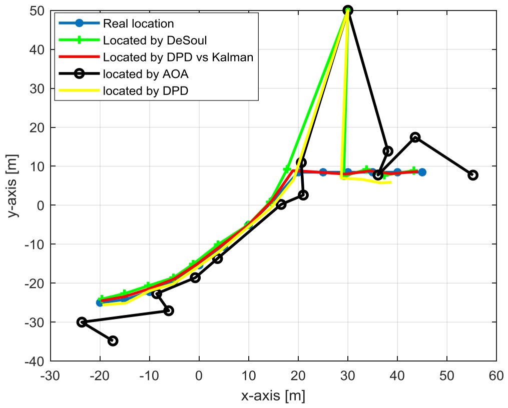

Figure 4. *The displacement trajectory of the emitter in case 2.*

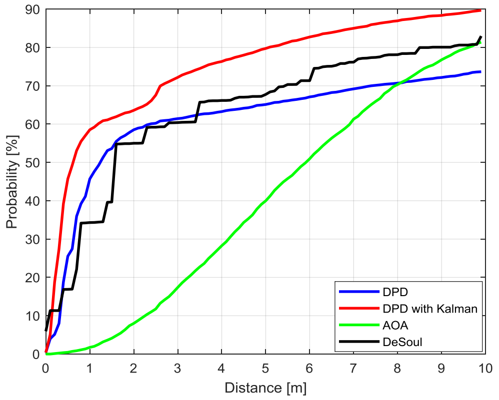

Figure 5. *The RMS error probability between the proposal approach to the others in case 2.*

In this case, we have used the same initial parameters in case 1. However, we consider the case that the movement trajectory of the emitter has been absented LOS path. Figure 4 depicts the displacement trajectory of the emitter in case 2.

The figure 5 shows the RMS error probability of the proposed approach and DPD, DiSoul, and traditional AOA in case 2. However, the proposed approach has still estimated the position of the source and the trajectory it closely follows the real trajectory of the source. The error in the range of less than 1 m, the proposed solution achieves significantly higher accuracy than the DPD, the DiSoul, and AOA.

5. CONCLUSIONS

This paper has solved the problem of narrowband localization in the presence of multipath, through the combined approach of direct localization and Kalman filter in an indoor environment. The simulation results have shown that the proposed approach is also remarkably robust to calibration errors. We have proposed a direct position determination based on the combination of the DPD technique and Kalman filter for localizing the emitter that can move following a random trajectory. This technique can determine the emitter more accurately than the DPD, DiSoul, and traditional AOA approaches. Especially, the proposed approach provides more efficient accuracy than other approaches when the transmission environment does not exist any the LOS path.

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TÓM TẮT

Phương pháp tiếp cận xác định vị trí trực tiếp hiệu quả để nâng cao tính chính xác cho hệ thống định vị trong nhà

Trong bài báo này, một phương pháp xác định vị trí trực tiếp hiệu quả, dựa trên mô hình kết hợp sử dụng bộ lọc Kalman đã được đề xuất. Cách tiếp cận được đề xuất cho phép ước tính chính xác vị trí bộ phát trong các tình huống khác nhau. Hai kịch bản đã được tạo ra để đánh giá hiệu suất của phương pháp tiếp cận của chúng tôi trong trường hợp tồn tại đường nhìn thẳng(LOS) và không tồn tại đường nhìn thẳng trên quỹ đạo chuyển động của bộ phát trong môi trường trong nhà. Kết quả mô phỏng cho thấy rằng, cách tiếp cận được đề xuất đạt được độ chính xác cao hơn so với các kỹ thuật góc đến (AOA), xác định vị trí trực tiếp (DPD) và định vị nguồn trực tiếp (DiSouL) trong cùng một kịch bản. Đặc biệt, khi sai số yêu cầu nhỏ hơn 1m và môi trường không tồn tại đường dẫn LOS, phương pháp đề xuất có xác suất đạt được độ chính xác khoảng 60% so với 1%, 35% và 45% của AOA, DiSoul, và DPD, lần lượt tương ứng.

Từ khoá: Định vị trong nhà; Định vị trực tiếp; Bộ lọc Kalman.