NOVEL SINGLE CHANNEL DIRECTION FINDING SYSTEM BASED ON PHASE ESTIMATION USING GENETIC ALGORITHM

HỆ THỐNG ĐỊNH HƯỚNG ĐƠN KÊNH MỚI DỰA TRÊN PHƯƠNG PHÁP ƯỚC LƯỢNG PHA TÍN HIỆU SỬ DỤNG THUẬT TOÁN DI TRUYỀN

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Abstract - Single channel Radio Direction Finding (DF) system has much more advantages such as more mobility and lower power consumption than Multi – channel DF system. In this paper, we propose a novel single DF system, which estimates the Direction Of Arrival (DOA) of incoming signal received by an M-element uniform circular antenna (UCA) array with a commutative switch followed by single channel Software Defined Radio (SDR) receiver. In this structure, the phase of the signal at each antenna element is estimated by Genetic Algorithm (GA) and then is processed to calculate the DOA information. By using GA, the DF system can operate with the lower convergence time in comparison with other single channel systems such as Phase Locked Loop or DFT based. Furthermore, this method can also extract the DOA with the small number of snapshots of signal. This fact means that the sampling frequency as well as the buffer capacity can be considerably reduced. The simulation results for DOA using the proposed approach will be shown and analyzed to verify its performance.

Keyword – Software Defined Radio (SDR), Direction Of Arrival (DOA), Uniform Circular Antenna Array (UCA), Genetic Algorithm (GA), Direction Finding (DF). Tóm tắt – Các ưu điểm của hệ thống định hướng vô tuyến đơn kênh so với các hệ thống định hướng đa kênh có thể kể đến đó là tính linh động và khả năng tiết kiệm năng lượng tiêu thụ. Trong bài báo này, chúng tôi đề xuất một kỹ thuật mới áp dụng cho các hệ thống định hướng vô tuyến đơn kênh được thiết kế dựa trên công nghệ vô tuyến điều khiển bằng phần mềm nhằm ước lượng hướng sóng tới của các tín hiệu được thu bởi dàn ăng ten đồng dạng tròn gồm M phần tử. Trong hệ thống này, pha của tín hiệu tới từng phần tử ăng ten sẽ được ước lượng dựa trên thuật toán di truyền để từ đó xác định ra hướng tới của tín hiệu. Bằng cách sử dụng thuật toán GA, hệ thống sẽ xác định được hướng của tín hiệu tới nhanh hơn so với các hệ thống áp dụng thuật toán DFT hoặc sử dụng các bộ vòng khóa pha. Các kết quả mô phỏng việc ước lượng DOA sử dụng phương pháp đề xuất sẽ được phân tích và đánh giá trong bài báo này.

**Từ khóa –** Vô tuyến điều khiển bằng phần mềm (SDR), Hướng sóng tới, Dàn ăng ten đồng dạng tròn đều (UCA), thuật toán di truyền (GA), định hướng sóng tới (DF).

# Introduction

Radio Direction Finding (DF) is a technique that identifies the bearing angle or the coordinates of incoming radio signals. The most important information estimated by a DF system is the Direction of Arrival (DOA). There are several ways to classify the DF systems. Based on system architecture, the DF systems can be divided into 2 types: Multi – channel system and Single channel system. In multi – channel system, multiple radio receivers are connected to the elements of an antenna array, respectively. Whereas, the single channel use only one receiver connected to an antenna array by a radio frequency switch. Because of this reason, the single channel system is smaller and it can offer some benefits such as more mobility and lower power consumption than Multi – channel DF system. Based on the signal processing manner, the DF systems can be classified into two main categories: amplitude comparison based [1] and phase comparison based [2-5]. Some other algorithms can be the hybrid of the two such as the Correlative vector method [6]**.**

In [2-5], a single channel phase comparison DF algorithm known as the phase locked loop algorithm is introduced. This method utilizes a bank of Phase Locked Loops (PLLs) to calculate the differential phase of signal received by an M – element uniform circular antenna array with a commutative switch followed by single channel Software Defined Radio (SDR) receiver. The differential phases are then processed by low complexity DF algorithm [5] to estimate the DOA information. In fact, one important factor when using phase locked loop is the requirement of small convergence rate of the algorithm compared to the switching cycle. Moreover, the PLLs need the large number of snapshots, the number of samples in sampling process, to track the phases of received signal. That is why we need to have a simpler complex in computation of phase information.

In [7-11], GA is used as an effective optimal solution. In communication, GA has been used for various applications such as signal parameters estimation [11] or channel identification [9]. This algorithm is based on the genetic principle of adaptation and survival of the fitness individual in the nature. In the natural selection issue, the mother of nature makes an examination of all possible situations, selects the appropriate trends and removes the others to produce more adaptable and evolutionary community with higher adaptive coefficient. Based on this mechanism, in the optimal problem, the GA regards the object of the problem as a chromosome which is the characteristic of an individual. The GA works with a community with many individuals and it has to find a particular individual which is true or the most similar to the object of the problem. In order to do that the GA firstly creates the initial population, which has the specific quantity with the random values in the given range. After that the GA will produces the successive generations of the population by using the genetic operators such as mating, crossover and mutation. In each generation, some individuals are selected according to their high value of fitness function in order to contribute to the next generation. The Fitness function is the function that is used to assess the suitability of an individual for a certain criteria of the population. This procedure will stop when the value of the fitness function of a particular individual is equal to or approximate the ending condition with the given error, in which the ending condition is defined as the most desire value of the Fitness function for overall procedure.

In this paper, we propose a novel single DF system which estimates the phases of an incoming signal by using Genetic Algorithm (GA) and then calculate the DOA information by the low complexity phase based DF algorithm [5]**.** This system combines the advantages of both the GA and the low complexity phase based DF algorithm. Therefore, its performance will be better than other single channel systems such as Phase Locked Loop or DFT based.

The paper is organized as follows. Section II describes the system architecture and model of the incoming signals. In section III, we present in detail the GA technique for phase estimation. Section IV reviews the low complexity phase based DF algorithm. The simulation results are shown in the section V. The conclusion is given in the section VI.

# System Architecture And Signal Model

* 1. *System architecture*

The proposed DF system architecture is shown in Fig.1. We model the DF system, including of an eight element circular antenna array connected to a single channel software defined radio receiver by a digital 8-to-1 switching circuit which switches sequentially around the elements

In Conventional DF systems, there are two common types of the antenna array: Uniform Circular Antenna (UCA) and Uniform Linear Antenna (ULA). In general, with the same number of elements and the same spacing between adjacent radiators, UCA has a smaller size than ULA. Moreover, by using the UCA array, the angle of arrival of incoming signals can be determined from all directions in the azimuth plane. Meanwhile, when using the ULA array, the DOA information is only estimated from to . That is why the UCA is of very practical interest and is often adopted in radar and sonar systems as well as in communication system for 3D channel modeling purpose.

The receiver will filter out and convert the RF signal to a complex base-band signal. This signal is then fed into phase estimation block which is used to track the phase of the incoming signal at each element. The tracked phases are processed by the DOA processing block to produce DOA information.

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| hinh1system_arch.emf |
| ***Fig. 1.*** *DF system architecture* |

* 1. *Signal model*



***Fig. 2.*** *Antenna array in the coordinate system*

In our research, we utilize the Uniform Circular Antenna Array (UCA) model, which includes a set of M isotropic antenna elements spaced around a circle with fixed radius R. We have defined the reference point as the origin of the three – Dimensional – Cartesian – coordinate system shown in Fig.2.

Assuming all signals impinging on the array are narrowband signals. For an M – element array depicted in Fig.1, let be the DOA in azimuth, be the DOA in elevation. The phase difference between any antenna and the reference point is given by

|  |
| --- |
| , (1) |

where ,, are the three – dimensional – coordinate of each antenna element and is the propagation factor. Defining the array – manifold vector for an M – element array as

|  |  |
| --- | --- |
| , | (2) |

where is the phase response at antenna relative to the reference point:

|  |  |
| --- | --- |
| . | (3) |

The single signal received by the array is , where is the gain of antenna and is the complex baseband envelope of an incoming signal. The envelop has assumed form

|  |  |
| --- | --- |
| . | (4) |

where is data related to modulation, either real or complex, and is the phase offset due to an arbitrary propagation distance of the signal.

In this paper, we only concern with the signal coming on the same plane of the array. Therefore, and . If it is assumed that spatial coordinates of a Uniform Circular Array with M elements are

|  |  |
| --- | --- |
| , | (5) |
| , | (6) |

and according to Equations (1, 3, 5 and 6), the single signal collected by antenna element in AWGN channel is given by

|  |  |
| --- | --- |
| , | (7) |

where , ℰ is a noise vector and is the carrier wavelength.

# Phase Estimation Using Genetic Algorithm

Based on Equation (7), it can be seen that the is the amplitude and the initial phase of the incoming signal at each antenna element is

|  |  |
| --- | --- |
| . | (8) |

If the phase component is estimated, the DOA information will be extracted as follow

|  |  |
| --- | --- |
| . | (9) |

where .

In order to do that, in this paper, the GA will be implemented to estimate the initial phase of the incoming signal. The procedure of method can be described as a diagram shown in Fig.3.

According to the diagram, the proposed method can be interpreted as the steps follow:

***Step 1 – Parameters establishment:*** This step establishes the necessary information, which includes received signal data, initial population, the number of generations, and Ending conditions, to execute the GA.

*Received signal data:* The received signal as in Equation (7) can then be sampled with period at discrete time instants . The discrete sampled form of the output signal at each antenna element is given as

|  |
| --- |
| thuattoan.emf |
| ***Fig. 3.*** *Phase estimation method diagram using GA* |

|  |  |
| --- | --- |
|  | (10) |

Each sample of the output signal is defined as one snapshot of data which will be processed to produce the DOA information. It can be simply expressed as

|  |  |
| --- | --- |
| = . | (11) |

*Initialize population*: In the phase estimation problem, the initial population is a random number of individuals vector. The individuals compound the random phase values in range of . And the random phase matrix can be written as

|  |  |
| --- | --- |
|  | (12) |

*Number of generations:* This factor determines the number of iterations of the procedure will be repeated. Obviously, if the number of generation increases, the accuracy and the execution time of the method will increase. Therefore, the trade – off between the computation time and the accuracy of the algorithm should be taken into account.

*Ending conditions establishment:*the search procedure will stop when the following results achieved:

* If the Fitness value is approximate maximum value of Fitness function with the predefined error, i.e., .
* If the total number of generations have completed.

***Step 2 – Fitness evaluation:*** In this step, the Fitness function is evaluated to find out the fitness of each particle. According to the [8], the fitness function is defined as:

|  |  |
| --- | --- |
|  | (13) |

where and can be written as

|  |  |
| --- | --- |
|  | (14) |

in which is the received signal as in Eq. 9 and is given as

|  |  |
| --- | --- |
|  | (15) |

***Step 3 – Natural Ranking:*** The Fitness values estimated in step 2 will be stored and sorted in descending order. The corresponding individuals with their phase values are arranged in the same order.

***Step 4 – Termination:*** If the Ending condition is reached, phase value of the first sorted individual will be chosen and stored as the most appropriate phase. On the other hand, the search procedure will continue to the next steps.

***Step 5 – Regeneration:*** Based on the ranking table received from step 3, some individuals, who have the highest fitness values, will be selected to create the next generation. Regeneration mechanism uses GA operators such as mating, crossover and mutation [7-8]. And then the step 2 will be repeated to process the new generation.

# Doa Estimation Algorithm

According to the Equation (9), the DOA information could be easily calculated after estimating the phase of the incoming signal at each antenna element. However, is unknown. Moreover, if the incoming signal is modulated, the true phases of the received signal at each antenna element can be rewritten as

|  |  |
| --- | --- |
|  | (16) |

where is factor of modulation (i.e. in case the modulation type is BPSK). However, we do not know about .

Because of the above analysis, we cannot immediately get the true DOA by the recorded phases from the Phase Estimation Block. Based on [5], the DOA information could be estimated as the steps as follow.

After being tracked, the phases will be differentiated to remove the phase offset occurring in all phases. We consider “the first target difference curve” as

|  |  |
| --- | --- |
|  | (17) |

In case of the data modulation, “the first given difference curve” is given as

|  |  |
| --- | --- |
|  | (18) |

Our objective is to find the . Although the difference has much larger range than , this sequence is still found by the following way.

In case of level modulation and antenna elements, we have phase difference values. From the first to the last antenna element, we assume that one of different values occur at that element. We use the assumed value of to calculate a value of possible DOA. We consider this DOA as assumed DOA obtained by using Equation (18) in which is a point on “the first given difference curve”. After that, based on Equation (17), we calculate the possible target difference curve corresponding to the calculated assumed DOA. Then we use the given curve and the possible target curve to estimate. The target curve is added by and the squared error of the target curve and the given curve are calculated. We choose the sequence. We choose the sequence or which the value of squared error is minimized. After finding the correct sequence of , the target difference curve can be represented as vector

|  |  |
| --- | --- |
|  | (19) |

The FFT of this vector is

|  |  |
| --- | --- |
|  | (20) |

All of are zeros except

|  |  |
| --- | --- |
|  | (21) |

Thus the estimated DOA is

|  |  |
| --- | --- |
|  | (22) |

# Simulation Result

The proposed method is simulated using Matlab to examine its performance for in both phase and DOA estimation. In this paper, we assume a radio signal impinging on an 8 – element antenna array with a radius, where is the signal wavelength, for good correlation and to get the appropriate mutual coupling factor between the antenna elements.

In the first simulation, the method is executed to estimate the DOA of the incoming signal at with 50 individuals using 20 snapshots and 20 generations. Figure 4 shows the real received phases and estimated phases by the phase estimation block. The “Expected phases” presents the real phases of the signal at each antenna element. The “Actual phases” plots the outputs of phase estimation block. In Fig.4, it can be seen that the estimated phase and the real incoming phase could be different. This fact is due to in the Initial population, the assumed phases are chosen in the range of . If the real phase of the signal at each antenna is outside of range , the search mechanism will map the phase back by subtracting or adding . Thus, the phases coming from Phase estimation block and the real phases can differ by

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| --- | --- | --- | --- | --- |
| fig4.png | | | | |
| ***Fig. 4.*** *Real and estimated phase at each antenna* | | | | |
| ***Table 1.*** *Recovering time for the implemented algorithms* [11] | | | |
| Benchmark test | Algorithm recovering time (s) | | |
| GA | PLL | DFT |
| Magnitude | 0.001042 | 0.026563 | 0.019271 |
| Phase | 0.011929 | 0.064583 | 0.020833 |
| Frequency | 0.008854 | 0.078646 | 0.021751 |

In comparison with other solutions in phase estimation, the convergence rate of GA is quite smaller than others such as PLL and DFT. The authors of [[11](#Sil13)] had proved that with their simulation results were stored in table 1. Obviously, with the smaller convergence rate, the DOA information will be extracted by GA more quickly than others.

Figure 5 shows the simulation result at DOA = in the AWGN channel in which the SNR is set to 10dB. The estimated DOAs in the simulation are the numerical values as in Equation (22). However, in order to demonstrate visually the result, we illustrate the DOA in XOY plane, in which the X – Axis is the DOA of incoming signals and the Y – Axis is the indicating factor. This factor is set to 1 corresponding to the estimated DOA in X - Axis. We can see that the DOA of signal of interest is estimated accurately by the proposed algorithm with very small error.

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| hinh5_30do.png |
| ***Fig. 5.*** *DOA estimation at 30o* |

In order to evaluate the influence of the number of snapshots on the performance of this algorithm, we execute this method to estimate the DOA at in the AWGN channel in which the SNR is set to 10dB with the variable number of snapshots. The simulation results shown in the Fig.6 indicated that the DOA information can be evaluated correctly with quite small snapshots.

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| --- |
| hinh6.png |
| ***Fig. 6.*** *Estimation accuracy at the DOA of 30o with the different number of snapshots* |

The number individuals in each generation could also affect to the performance of the proposed DF system. Figure 7 presents the simulation result of DOA estimation at with the difference number of individuals with 20 generations. In this figure, it can be seen that the proposed DF system need at least 8 individuals to extract the DOA information. Moreover, when the number of individuals is greater than 10, the accuracy of in DOA estimation seems to be constant.

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| --- |
| DOA_indi2.png |
| ***Fig. 7.*** *Estimation accuracy at the DOA of 30o with the different number of individuals* |

Furthermore, the impaction of the number of antennas on the DOA estimation is also a factor to be assessed. The simulation result is indicated in Fig.8. In this simulation, the method is executed with the number of antennas varying from 2 to 8 to estimate the DOA of . It can be seen that the proposed algorithm operates well when the number of antennas are more than three. However, with quite small number of snapshots (20 snapshots), the DF system can quickly estimate the DOA of the incoming signal.

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| antennas.png |
| ***Fig. 8.*** *Estimation accuracy at the DOA of 30o with the different number of antennas* |

In the remainder part of our work, we verify the performance of the proposed DF system in the AWGN channel with varying SNR. The simualtion result is plotted in Fig.9. It is clear to see that the performace of proposed system is quite good and stable in the AWGN channel.

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| fig9_errror_snr.png |
| ***Fig. 9.*** *Estimation accuracy at the DOA of 30o in AWGN channel* |

# Conclusions

In this paper, we propose a new single phase based DF system using Genetic Algorithm. By using GA, the DF system can operate with the smaller snapshot, thus improve the convergence time in comparison with Phase Locked Loop based system. This fact means that the sampling frequency as well as the buffer capacity can be considerably reduced. By this way, The proposed system with low complexity can be implemented for real time application.

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