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An Ameliorated GWO-SQP Model for Enabling an Effective Radar Communication in MIMO Systems

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Abstract: One of the most demanding and important tasks in Multiple Input Multiple Output (MIMO) radar systems is the design and development of Orthogonal Frequency Division Multiplexing (OFDM) – Linear Frequency Modulation (LFM) waveforms. Also, increasing the pulse characteristics of spatially synthesized signals is crucial in MIMO systems since it makes it possible to successfully eliminate grating sidelobes. Various joint optimization strategies have been developed in the existing studies to enhance the overall performance of radar communication systems. It still has limitations due to issues with difficult to comprehend calculations, a high error rate, and reduced performance. To enhance the pulse compression qualities and suppress grating sidelobes, the proposed research work aims to implement a Gray Wolf Optimization (GWO) – Sequential Quadratic Programming (SQP) mechanism. In this particular instance, the modification is carried out to optimize the frequency steps of the anticipated LFM waveform with balanced orthogonal and sidelobe features. By using different pulse compression properties, the performance and results of the proposed GWO-SQP based joint optimization model are evaluated and compared through simulation analysis. The results show that, in comparison to the previous methodologies, the proposed optimization model offers better performance outcomes. For comparative assessment, the parameters such as maximum ASP, mean ASP, and mean CP are validated and compared for the existing and proposed models with respect to different Bs(MHz) including 2.72, 2.44, 2.16, 1.81 and 1.46. The results indicate that the proposed GWO-SQP could effectively reduce ASP with the average values of 0.12 (Max ASP), 0.10 (Mean ASP) and 0.32(Mean CP) values respectively.

Keywords: *Multiple inputs and outputs (MIMO), Radar Communication, Spatial Synthesis Signals, Orthogonal Frequency Division Multiplexing (OFDM), Gray Wolf Optimization (GWO), and Linear Frequency Modulation (LFM).*

1. Introduction

In wireless communications, the Multiple Input Multiple Output (MIMO) system [1, 2] is an innovative antenna technology. It is a frequency selective for numerous path parameters and has a number of antennas on both the sending and receiving terminals. In wireless communication systems, Orthogonal Frequency Division Multiplexing (OFDM) [3] is used to achieve large data rates. The frequency selective channels are transformed into a parallel set of bands using a MIMO and OFDM technology. MIMO radar [4, 5] uses multiple types of waveforms for transmission and has the ability to receive signals that have been collaboratively processed by a number of receiving antennas. It makes use of widely spread transmitters and receivers to see the target from a number of distinct angles, creating spatial variety that can improve radar detection effectiveness. Research on the design of the OFDM LFM waveform has recently attracted a lot of attention. An OFDM radar signal is generated in the context of multipath reflections to find moving targets. The spectrum of an OFDM waveform [6] can be designed using an evolutionary process, which will improve the radar's wideband ambiguity function. The spatially synthesized signals of the OFDM-LFM waveform [7, 8] have very low pulse compression qualities or large grating sidelobes, it results in high false alarms and weak target embedding in target identification for real-world applications [9]. As a result, various techniques for conquering this problem have been developed in the existing studies. Additionally, a number of objective type optimization methods have been developed in previous studies for building OFDM-LFM waveforms with good pulse compression characteristics of the spatial synthesized signals.

Typically, pulse compression can improve radar's range resolution and signal-to-noise ratio (SNR) of the return signal [10, 11]. In light of this, pulse compression is a key component of many modern radar applications, including target identification, mapping, and etc. The well-known matched filter approach was previously used to achieve pulse compression, and it can be used to improve the output SNR of the radar signal in an environment with white harmonic noise. The corresponding filtering will still also generate negatively high lower order harmonics. Since, the conventional techniques [12, 13] largely focus on signal processing methodologies, parameter setup, etc., the high grating sidelobes of the OFDM LFM waveform have not yet been described. The proposed work attempts to develop a novel joint optimization model for OFDM-LFM waveforms with enhanced pulse compression properties. A decreased

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sidelobe level, a constant envelope, and orthogonality are further goals of the presented system [14]. The following are the paper's main contributions:

- The proposed framework significantly enhances the effectiveness of radar communication by using Linear Frequency Modulated (LFM) signals.
- A computationally effective Gray Wolf Optimization (GWO) algorithm is employed for generating the best OFDM-LFM signal.
- To successfully reduce the side lobes, a GWO algorithm is integrated with the Sequential Quadratic Programming (SQP) technique.
- A thorough simulation is carried out with various parameters to assess the viability and efficacy of the proposed communication model.

The rest of this article has been split into the following sections: The effectiveness of radar communication in MIMO-OFDM systems is evaluated in Section 2 using a variety of optimization techniques. A complete description of the GWO-SQP communication system is given in Section 3. In Section 4, several parameters are used to validate the simulation and comparison results of the proposed GWO-based communication systems. The overall article and its future scope are summarized in Section 5.

2. Related Works

This section looks at a few of the conventional optimization techniques used in MIMO-OFDM communication systems in order to guarantee an effective radar transmission. It also considers the advantages and disadvantages of each mechanism in light of its distinctive features and main goals.

Ma, et al [15] developed an integrated waveform design using BPSK communication model for MIMO-OFDM communication system. The problems of low signal transfer rate and low spectral efficiency can be properly resolved by multi-carrier modulation technology in OFDM technology. The transmission rate and spectrum efficiency of communications can be significantly increased by using an OFDM-BPSK-LFM signal, where the functionality of the radar's fuzzy function remains constant. *Rao, et al* [16] developed a hybrid Particle Swarm Optimization (PSO) method for obtaining high data rate in MIMO communication system. The authors mainly concentrated on improving the power allocation in the communication systems with reduced Bit Erro Rate (BER) and channel estimation error rate. For accomplishing this objective, the PSO algorithm is utilized in this study. *Zhao, et al* [17] implemented a piecewise nonlinear frequency modulation mechanism for enabling better communication in MIMO radar systems. Here, the signal optimization is carried out with the use of PSO algorithm. To make a radar sensor that is more effective, sidelobes in MIMO radar systems must be reduced by waveform design. Hence, the authors intends to use a PSO algorithm for reducing sidelobes with proper waveform design. *Wu, et al* [18] modeled an optimization problem for proper waveform design in MIMO-OFDM systems. *Wang, et al* [19] used a sparse array optimization mechanism for MIMO radar communication. An antenna displacement in a sensor array produces distinct phases that allow for array design for symbol embedding. In this scenario, waveform-antenna paring with array reconfiguration for communication symbol embedding in MIMO radars is carried out using a hybrid selection and permutation technique, which can lead to a high data rate and significantly lower symbol error rate. *Shi, et al* [20] designed a offset quadrature amplitude modulation mechanism for satisfying the requirements of radar communication. Here, both the cyclic and multiplier algorithms have been implemented to obtain the best solution for joint radar communication. *Rao, et al* [21] utilized a PSO based power allocation mechanism for MIMO communication systems. Moreover, the authors aim to minimize the BER and improve the SNR by effectively allocating power at both transmitter and receiving ends based on the optimal solution provided by PSO. To improve the detection performance and communication capabilities of radar, Temiz, et at [22] created the Radar communication precoder system. The main goals of this work were to maximize communication, minimize complexity, and guarantee energy efficiency. To reduce the need for UEs, the best beam power allocation was also carried out. Some of the recent optimization techniques used in the existing studies for MIMO-OFDM communication are surveyed in Table 1 with its pros and cons.

Table 1. Study on the existing optimization techniques used in MIMO-OFDM systems

Techniques	Positives	Negatives
Genetic Algorithm (GA) [23]	It requires very few parameters for optimization, and better optimal solutions.	Slow in process, and more difficult to understand.
Gradient Descent (GD) optimization [24]	Better stability in convergence, and computationally efficient.	High time consumption for reaching optimal solution in the searching space.
Firefly Algorithm (FA) [25]	Better efficiency and small number of iterations.	Local optimum, and low convergence rate.

Bee Colony Algorithm (BCA) [26]	Better exploration capability, and simple to implement.	Slow convergence and not suitable complex problems.
Swarm Optimization (SO) [27]	Self-organizing nature and better efficiency.	Local optimum, and not scalable.
Cuckoo Search (CS) algorithm [28]	It requires few parameters to tune, and easy to deploy.	Low searching speed, and high time consumption.
Flower Pollination (FP) algorithm [29]	Better efficiency and accuracy.	Poor exploitation capability, and not suitable for complex engineering problems.

3. Proposed Methodology

The proposed GWO-SQP based MIMO communication system is fully explained in this section, along with a description of the system's overall functioning and all necessary information. The main contribution of this research is the development of an efficient joint optimization approach that uses Gray Wolf Optimization (GWO) and Sequential Quadratic Programming (SQP) algorithms to produce the optimum OFDM-LFM waveforms. It also seeks to identify the frequency codes and phases that will result in the best orthogonal sidelobe suppression for high grating sidelobes.

3.1. Radar Signal Modeling using OFDM-LFM

One of the prominent methods for reducing the peak power of radar is pulse compression, which is widely utilized in communication systems. Longer pulses can be used properly since they are used at the transmitter side during regulating activities. In MIMO systems, a variety of carrier frequencies can be used by the transmit antennas to send the OFDM-coded waveform and its main function is to exchange fixed frequency signals. Figure 1 displays an instance of LFM signals from the two distinct LFM models that have been generated using the matched filtering technique. The LFM signals are often composed of inphase and quadrature band signals, which are completely reliant on the scientific parameters of the chirp signal. It is also termed as a frequency balanced waveform since the carrier frequency can shift over time. The energy in this model is dispersed uniformly over the frequency ranges by using these waveforms, and the expression is represented mathematically as follows:

$$w_a(t) = r(t)e^{j2\pi(f_c t + (1/2)\mu t^2)} \tag{1}$$

$$r(t) = \begin{cases} 1, & -\frac{T}{2} \le t \le T/2 \\ 0, & Else \end{cases} \tag{2}$$

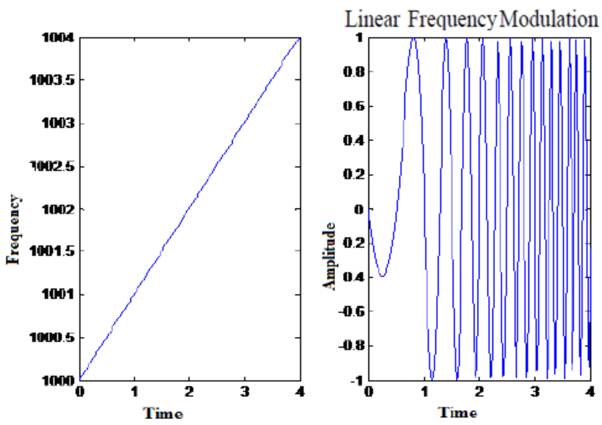
$$\mu = MB_w/T \tag{3}$$

$$f_c = f_p + c_a \Delta f \tag{4}$$

Where, $w(t)$ indicates the OFDM-LFM waveform, $r(t)$ is the rectangular window, T denotes the time period, $a = 1,2,\dots A$, μ represents the chirp rate, MB_w defines the modulated bandwidth, f_c is the carrier frequency, f_p indicates the centre frequency, c_a is the code of frequency, and Δf is the frequency step. According to the signal processing structure of radar communication system, the receiver beamformer by the space time matched filtering technique are as follows:

$$f(\theta, \theta_h, \tau) = \int_{-\infty}^{\infty} y(\theta, t) y^*(\theta_h, t-\tau)\, dt \tag{5}$$

Where, τ indicates the delay time, and θ_h is the direction of beam. If $\theta_h = \theta$, the pulse compression rate is obtained that is corresponding to the autocorrelation model of spatial synthesis signal. Else, the cross correlation function is obtained that lies in two different locations. By using the function $f(\theta, \theta_h, \tau)$, the process of target detection is enhanced for instance, the autocorrelation sidelobes may leads false detection, which creates the interference among various targets. The best way to analyze and optimize the autocorrelation function is the tuning of compression property for target detection as mentioned in equ (5).



(a) (b)

Fig 1. Sample LFM signals (a). Model 1 and (b). Model 2

3.2. Pulse Compression Analysis

The carriers are transmitted using a single communication line using a spread-spectrum technique known as OFDM. Similarly, each sub carrier may transport only a small percentage of the entire signal. The OFDM signals are often created using a modulation technique with the desired amount of bits, such as Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), and Quadrature Amplitude Modulation (QAM). Fig. 2 displays the fundamental block diagram of the OFDM system.

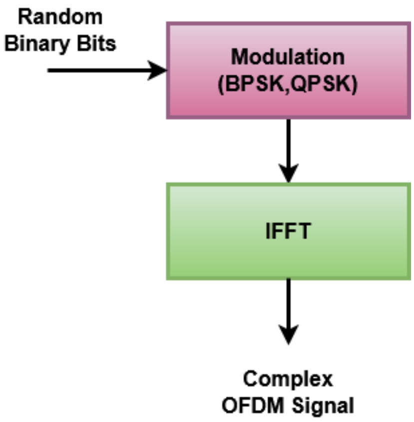


Fig 2. Structure of OFDM

Based on the signal model, the results of pulse compression of the spatial synthesized signal are analyzed, and the results are given in below:

$$f(\theta,\tau) = \sum_{m=1}^{M} e^{j2\pi f_m \tau}\,\zeta_0(\tau) + \sum_{v=1}^{M-1} R_v(\tau) + \sum_{n=1}^{M-1} Z_n(\tau) \quad (6)$$

where,

$$\zeta_u(\tau) = \int_{-\infty}^{\infty} r(t) r(t-\tau) e^{j\pi|\mu t^2 - \mu(t-\tau)^2|}\, e^{j2\pi u t} dt \quad (7)$$

$$R_v(\tau) = \sum_{a=v+1}^{A} e^{j2\pi f_{c-v}\tau} e^{\frac{j2\pi v d sin(\theta)}{\lambda}} \zeta_{f_c - f_{c-v}}(\tau) \quad (8)$$

$$Z_n(\tau) = \sum_{a=1}^{A-n} e^{j2\pi f_{c+n}\tau} e^{\frac{-j2\pi n d sin(\theta)}{\lambda}} \zeta_{f_c - f_{c+n}}(\tau) \quad (9)$$

The equ (5) represents the main lobe, while the last two terms portray the left and right side lobes respectively. Then, the frequency code c_a is set as $a-(A+1)/2$, hence the carrier frequency at a^{th} position is represented as $f_c = c_a\,\Delta f$. Based on these models, it is analyzed that the same frequency step and modulation bandwidth can create the grating sidelobes at disparate positions.

3.3. GWO-SQP based OFDM-LFM System

GWO is one of the most widely used optimization algorithm for solving complex engineering problems. The GWO is a brand-new member of the family of swarm intelligence-based optimization algorithms with various advantages, including enhanced convergence, optimum solution in less amount of time, and low complexity. It imitates the steps of tracking, encircling, and shooting used in wolf hunting. The gray wolf population has a rigid hierarchical structure, where the positions are determined by their fitness ratings. The GWO calculation mimics the wolf's chase mechanism and administration sequence. Alpha, beta, delta, and omega are four distinct gray wolves that must be considered in order to imitate the authority chain of control. Finding prey, encircling the prey, and assaulting the prey are the three key processes in the hunting process. When compared to the other optimization methods, the GWO has the specific benefits as listed in below:

- It requires minimal parameters for optimization.
- It follows simple principles, hence it is to implement/deploy.
- Best optimum solution with low computational complexity.

The three of these are used to carry out optimization techniques, which are denoted as $P(\alpha), P(\beta) and\ P(\delta)$. The velocities are determined by using the following equations:

$$V_\alpha = |C.P_\alpha(t) - P_i(t)| \quad (10)$$

$$V_\beta = |C.P_\beta(t) - P_i(t)| \quad (11)$$

$$V_\delta = |C.P_\delta(t) - P_i(t)| \quad (12)$$

Then, the positions are updated by using the following models:

$$P_1 = P_\alpha + B.V_\alpha \quad (13)$$

$$P_2 = P_\beta + B.V_\beta \quad (14)$$

$$P_3 = P_\delta + B.V_\delta \quad (15)$$

Where, B and C are the vector coefficients which are calculated by using the following models:

$$B = 2b.r_1 - b \quad (16)$$

$$C = 2.r_2 \quad (17)$$

$$P_{i+1} = \frac{P_1+P_2+P_3}{3} \quad (18)$$

The hybridization is performed based on the following models:

$$V_\alpha = w * vel_i(\tau) + r_1 * c1 * \left(pos^{lb1}(t) - pos_i(t)\right) + r_2 * c2 * \left(pos^{gb}(\tau) - pos_i(\tau)\right) \quad (19)$$

$$V_\beta = w * vel_i(\tau) + r_1 * c1 * \left(pos^{lb2}(t) - pos_i(t)\right) + r_2 * c2 * \left(pos^{gb}(\tau) - pos_i(\tau)\right) \quad (20)$$

$$V_\delta = w * vel_i(\tau) + r_1 * c1 * \left(pos^{lb3}(t) - pos_i(t)\right) + r_2 * c2 * \left(pos^{gb}(\tau) - pos_i(\tau)\right) \tag{21}$$

Consequently, the position updation is performed by using the following models:

$$P_1 = pos^{lb1} + B.V_\alpha \tag{22}$$

$$P_2 = pos^{lb2} + B.V_\beta \tag{23}$$

$$P_3 = pos^{lb3} + B.V_\delta \tag{24}$$

Where, B and C are the vector coefficients estimated by using the following models:

$$B = 2b.r_1 - b \tag{25}$$

$$C = 2.r_2 \tag{26}$$

$$P_{i+1} = \frac{P_1+P_2+P_3}{3} \tag{27}$$

$$E = \max_{\substack{p=1,2,\ldots,P \\ 0<\tau\le T}} \left|f(\theta_p,\tau)\right| \tag{28}$$

The radar communication system is better suited to the GWO and SQP combination because it uses GWO to optimize the frequency code and SQP to choose the phase vector. The flow of GWO algorithm is shown in Fig 3.

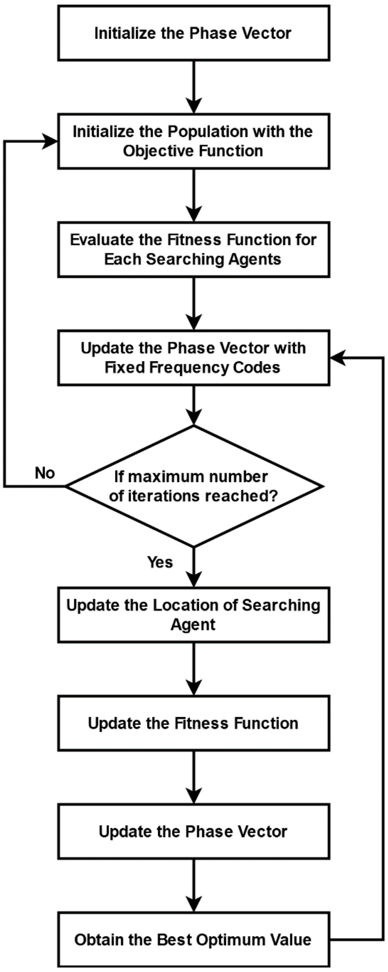


Fig 3. Flow of the GWO-SQP model

4. Results and Discussion

By using a range of evaluation metrics, this section compares and demonstrates the simulation results of the proposed radar communication technique. A few design examples are also used to show how well and effectively the proposed GWO-SQP handles the joint optimization procedure. The main purposes of this technique was to eliminate high grating sidelobes through frequency code and phase optimization, with a focus on pulse compression to improve reliable transmission. Here, the sidelobes of the grating are reduced using a modified optimization strategy. The general parameters taken into consideration by the GWO process include the initial population, the number of particles for phase optimization, and the best global function. Here, two LFM waveforms with Bs of 2.16 MHz and 2.79 MHz, respectively, have been generated for analysis. The average sidelobes of the waveforms are first determined for the proposed GWO-SQP based joint optimization technique, as illustrated in Fig 4. In this scenario, the proposed model may occasionally create more grating sidelobes than the conventional optimization methods. The inclusion of sink-like functions in the proposed model may lead to small peaks in the waveforms. In addition, the GWO-SQP model is used to synthesize the erroneous detection's waveforms that are primarily generated by the grating sidelobes.

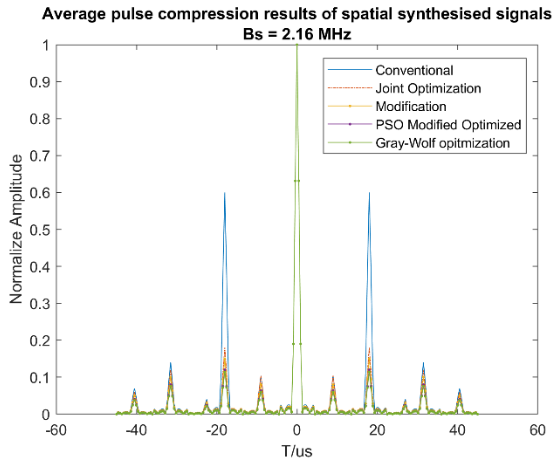
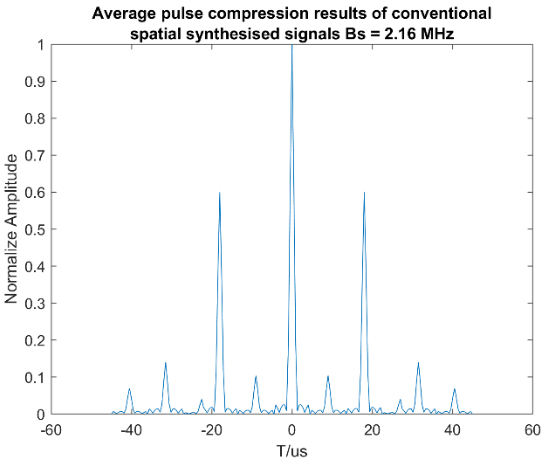


Fig 4. Average pulse compression results Bs = 2.16MHz

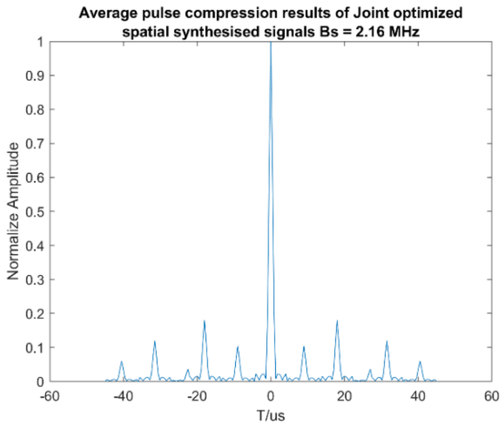
In the present study, the pulse compression characteristics of the spatial synthesis signals have primarily been utilized to measure the target detection performance of the optimization model. Additionally, using spatial cross correlation functions, the target detection performance at various targets is assessed. The pulse compression properties of the existing (i.e., convention, joint optimization, modified synthesized) and proposed GWO-SQP techniques are separately validated and compared in Figs. 5 and 6 with respect to Bs = 2.16GHz and Bs =

2.79GHz to demonstrate the efficacy of the proposed GWO-SQP model.



(a)

According to the estimated results, the proposed GWO-SQP technique has significantly improved pulse compression characteristics for both the LFM waveforms Bs = 2.16GHz and Bs = 2.79GHz. The proposed GWO-SQP technique overcomes the other techniques with improved results, because of its increased convergence speed and reduced local optimum.



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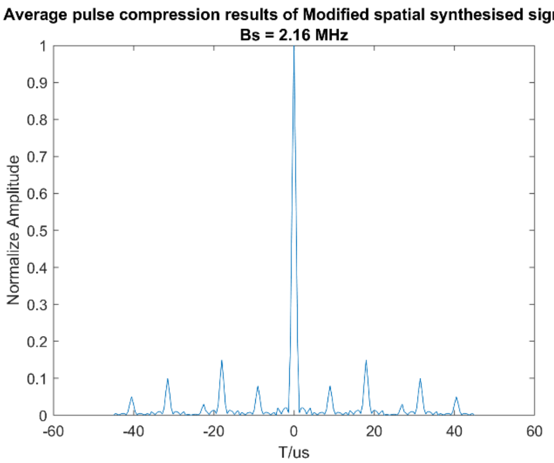

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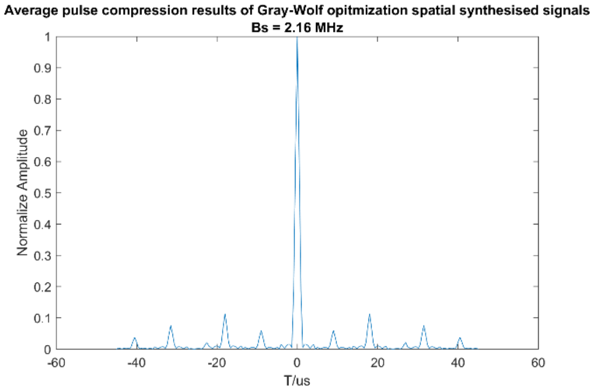
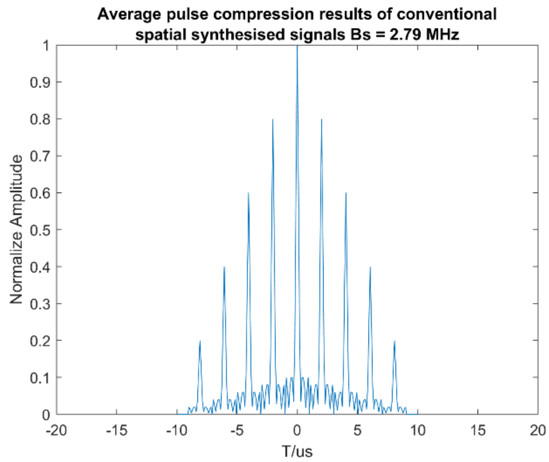
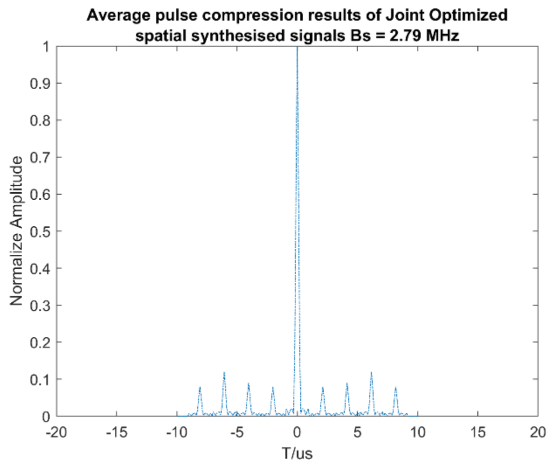


(d)

Fig 5. Average pulse compression analysis Bs = 2.16MHz (a) Conventional spatial synthesized signals (b). Joint optimization based spatial synthesized signals (c). Modified spatial synthesized signals, and (d). GWO-SQP based spatial synthesized signals



(a)



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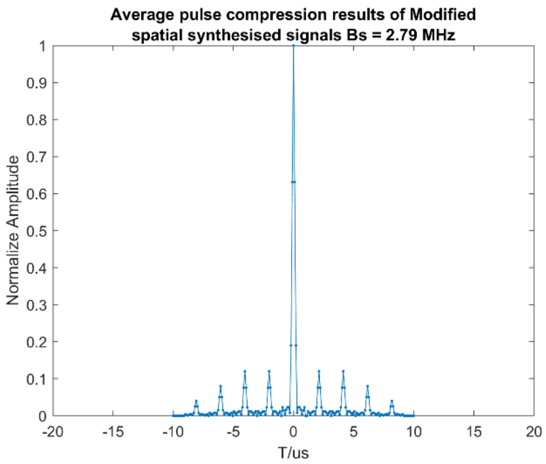

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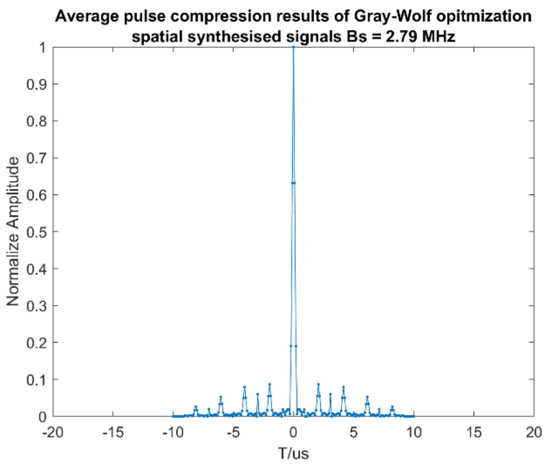
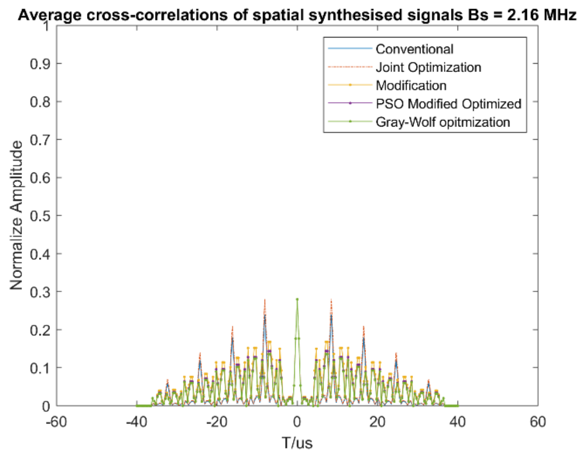


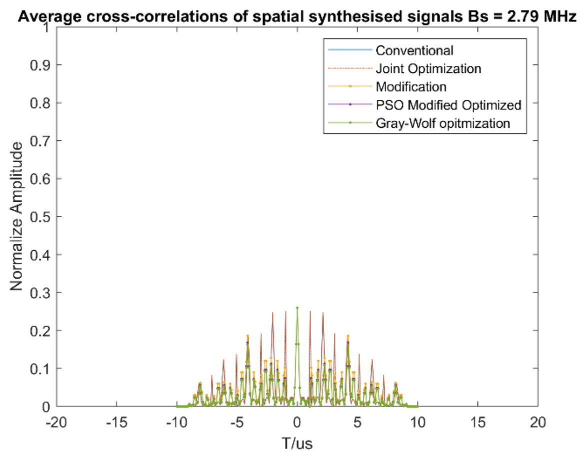
(d)

Fig 6. Average pulse compression analysis Bs = 2.79MHz (a) Conventional spatial synthesized signals (b). Joint optimization based spatial synthesized signals (c). Modified spatial synthesized signals, and (d). GWO-SQP based spatial synthesized signals

Similar to this, Fig. 7 (a) and (b) illustrate the average cross correlation analysis of the existing and proposed optimization procedures for both synthesized signals with Bs = 2.16 MHz and 2.79 MHz, respectively. In this study, the cross correlation levels of the developed waveforms are investigated, and it is discovered that, the existing approaches does not improve the property compared to the proposed model. As a consequence, the average cross correlation is independently computed for the conventional (conventional, joint optimization, modified synthesized signals) and proposed GWO-SQP approaches with Bs = 2.16MHz and Bs = 2.79MHz in Figs. 8 and 9, respectively. Overall, the outcomes show that the proposed GWO-SQP technique works better than the other models already in use, with enhanced cross correlation values for both LFM signals.

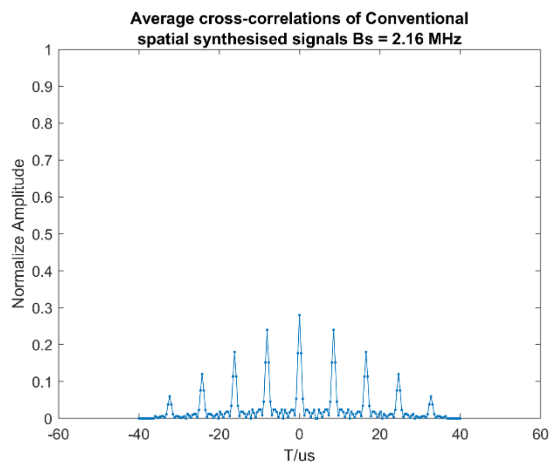


(a)

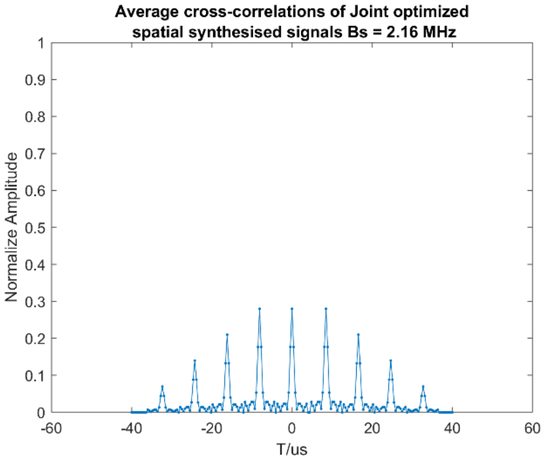


(b)

Fig 8. Average cross correlation analysis (a) Bs = 2.16MHz and (b) = 2.79MHz



(a)



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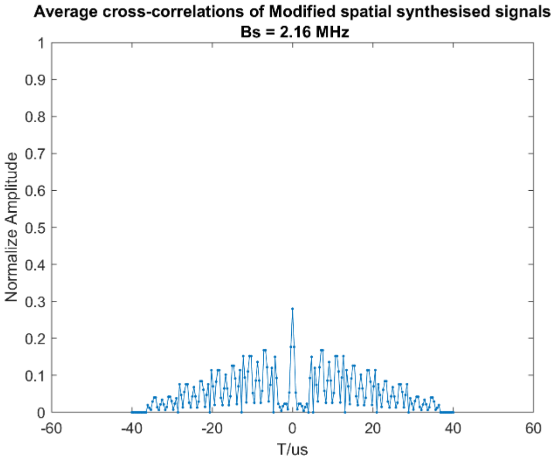

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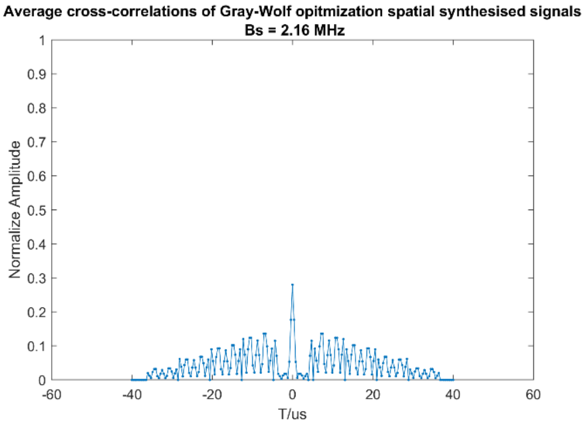
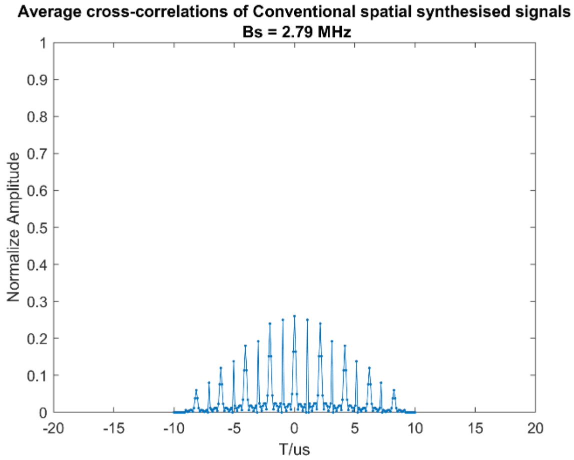
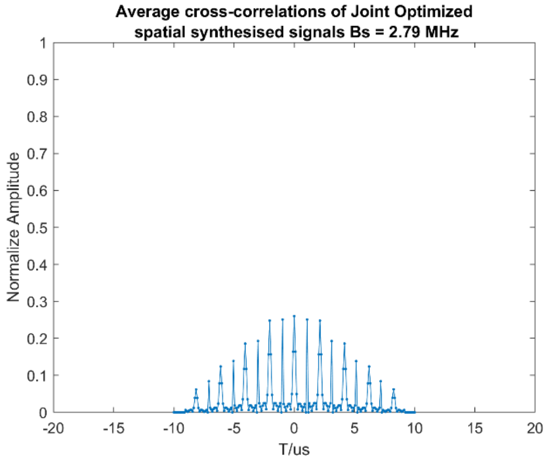


(d)

Fig 9. Average cross correlation results with Bs = 2.16MHz (a) Conventional spatial synthesized signals (b). Joint optimization based spatial synthesized signals (c). Modified spatial synthesized signals, and (d). GWO-SQP based spatial synthesized signals



(a)



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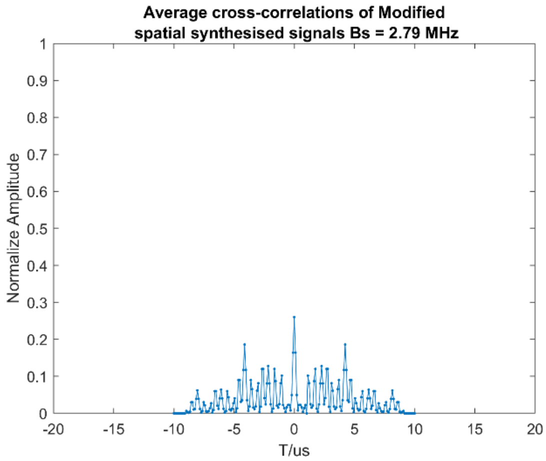

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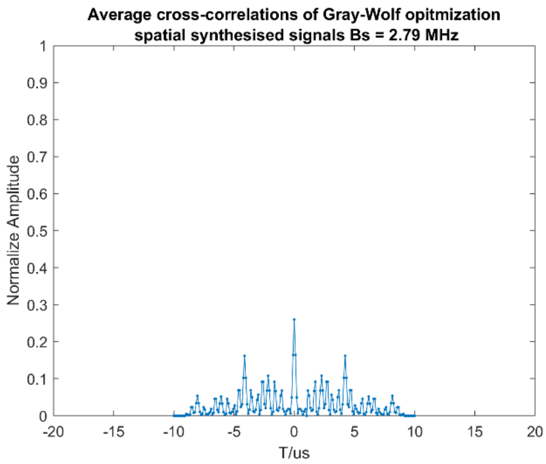
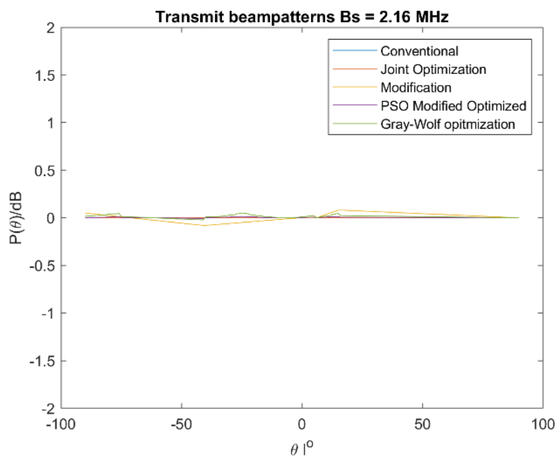


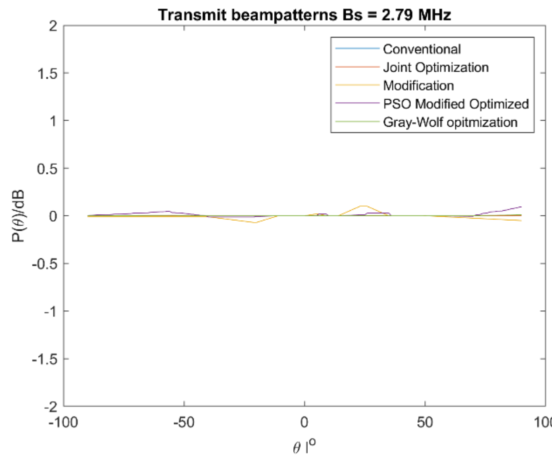
(d)

Fig 10. Average cross correlation results with Bs = 2.79MHz (a) Conventional spatial synthesized signals (b). Joint optimization based spatial synthesized signals (c). Modified spatial synthesized signals, and (d). GWO-SQP based spatial synthesized signals

Similar to the autocorrelation analysis, the grating loves are suppressed by the adjustments performed throughout the optimization process. The suggested method performs better in the cross correlation analysis as a result of the provided waveforms. In order to determine the difference between the joint optimization model and orthogonality, the transmit beam pattern analysis is carried out as shown in Fig 11. The findings demonstrate that both the proposed and existing models' transmit beam patterns are entirely orthogonal. They are generally orthogonal in the omnidirectional pattern, even though it is not satisfied in the modified waveform due to the reduction of frequency steps. The operation of grating sidelobes is illustrated by the pulse compression analysis in Fig 12. According to the analysis, sidelobes can be eliminated by using the joint optimization model to broaden the range of the modulation bandwidth and frequency step.

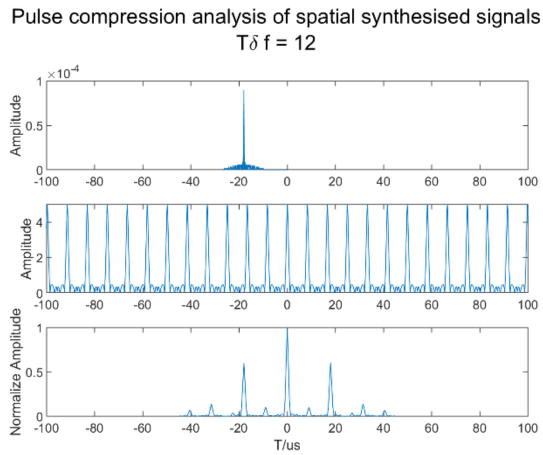


(a)

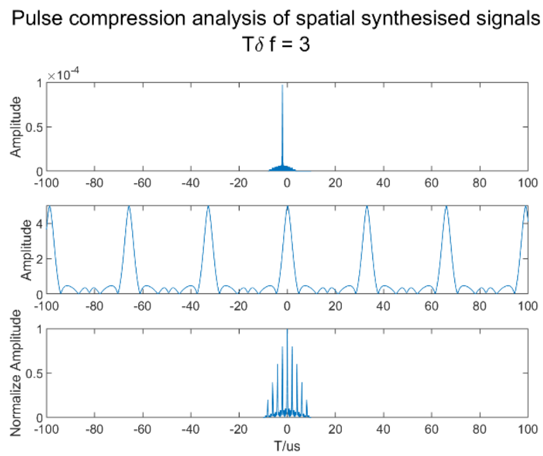


(b)

Fig 11. Transmit beam pattern analysis (a). B_s = 2.16 MHz and (b). B_s = 2.79 MHz



(a)



(b)

Fig 12. Pulse compression analysis (a) Tδf=2 and (b) Tδf=3

The time length, bandwidth, random numbers, and frequency steps are effectively optimized for designing the OFDM-LFM waveforms using the proposed GWO-SQP optimization model. As indicated in Table 2, the correlation properties taken into account in this analysis include the maximum ASP, minimum ASP, and mean CP, as well as the parameters of autocorrelation sidelobes, mean cross correlation peals, and mean ASPs. The findings show that the suggested GWO-SQP algorithm could successfully minimize the ASPs at various modulation bandwidths. As a result, the suggested joint optimization mode performs better than the current optimization strategies.

Table 2. Comparative analysis

Method	Bs, MHz	2.72	2.44	2.16	1.81	1.46
Conventional [30]	Max ASP	0.6499	0.4133	0.5208	0.2060	0.3399
	Mean ASP	0.6420	0.4102	0.5208	0.1994	0.3261
	Mean CP	0.5674	0.6405	0.5341	0.6525	0.6367
Joint Optimization [30]	Max ASP	0.2061	0.1745	0.1302	0.1148	0.1384
	Mean ASP	0.2036	0.1724	0.1288	0.1138	0.1373
	Mean CP	0.5539	0.5338	0.5292	0.5312	0.5366
Modified [30]	Max ASP	0.2381	0.1766	0.1376	0.1284	0.1232
	Mean ASP	0.2237	0.1748	0.1354	0.1274	0.1214
	Mean CP	0.4429	0.3639	0.3527	0.3503	0.3829
Optimization Modified (PSO-SQP)	Max ASP	0.1825	0.1602	0.1256	0.1053	0.1126
	Mean ASP	0.1856	0.1525	0.1156	0.1017	0.1021
	Mean CP	0.4251	0.3541	0.3421	0.3385	0.3592
GWO-SQP	Max ASP	0.1600	0.1417	0.1045	0.0919	0.0924
	Mean ASP	0.1612	0.1355	0.1014	0.0879	0.0906
	Mean CP	0.3989	0.3345	0.3268	0.3195	0.3410

5. Conclusion

This paper introduces a new optimization, named as, GWO based SQP mechanism for generating OFDM-LFM waveforms. The major goal of this optimization strategy is to enhance the pulse compression properties of the generated signals. Traditionally, a number of recent studies have focused on analyzing different ways to enhance the pulse compression characteristics in MIMO radar communication systems. Among others, the joint optimization is one of the greatest ways to select frequency codes and phases optimally in order to eliminate grating sidelobes with the ideal orthogonal characteristic. The key advantages of using the GWO-SQP mechanism are the enhanced convergence rate, processing speed, and capacity to discover the optimal solution with the fewest repeats. The efficiency of the GWO-SQP mechanism is validated through a complete simulation and, the results are compared to the standard joint optimization techniques based on the correlation characteristics. The outcomes demonstrate that the GWO-SQP mechanism is more effective than the current techniques and, it has better pulse compression properties. Future work on this research could involve the use of a novel hybrid optimization methodology to improve the performance of MIMO radar systems.

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