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EDITORIAL

Guest editorial: Advanced signal processing for integration of radar and communication (IRC)

Abstract
Radar and communication are two key applications of radio technology, and they occupy a large portion of the frequency spectrum. Traditionally, radar and communication systems are operated at different frequencies, owing to their different functions and application areas. For instance, radar was mainly employed for sensing (target detection, localization, recognition, imaging, etc.) in the military field, while wireless communication was mainly for information delivery. However, along with the fast development of radio technologies and huge demand for information, the radio frequency (RF) spectrum is becoming increasingly congested, and the spectra of the radar system will be overlaid with those of wireless communication devices. Moreover, radar and communication are becoming increasingly merged in both technologies and applications. Besides the military field, radar has been widely employed in daily life including weather service, air traffic control, autonomous driving and security monitoring. Meanwhile, these applications rely Largely on information transmission through wireless communications. In this regard, integration of radar and communication (IRC) has proved to be a very promising development to address the spectrum congestion issue between radar and communications devices. This also brings us a number of key challenges in signal processing for both implementation of IRC and joint optimization between the two systems.

This special issue aims at bringing together contributions from researchers and practitioners in the area of advanced signal processing for IRC. After careful peer reviews and revisions, 13 papers have been accepted for publication in this special issue. The selected papers are broadly categorised into four topics, that is, radar and communication coexistence, beamforming, target detection and parameter estimation, and waveform design. In what follows, papers in each topic are briefly introduced.

1 | COEXISTENCE BETWEEN RADAR AND COMMUNICATION

Yang *et al.*, in their paper "Spectrally compatible MIMO radar waveform design based on alternating direction method of multipliers", present the design of the MIMO radar waveform when there is coexistence between radar and communication systems. To perform the design, the output signal-to-interference-plus-noise ratio (SINR) of the MIMO radar is maximised under transmit energy, similarity and spectral compatibility constraints. An alternating direction method of multipliers (ADMM) algorithm is proposed to efficiently tackle the non-convex spectrally compatible MIMO radar waveform design problem in both single-antenna and multi-antenna scenarios. Due to the decomposability of ADMM, only a few quadratic programing subproblems need to be solved during each iteration in this algorithm, which reduces the computational complexity. Numerical simulations show that the proposed ADMM algorithm can achieve almost the same performance as the semidefinite relaxation (SDR) and existing ADMM algorithms, however, it is computationally more efficient.

Wei *et al.*, in their paper "Joint waveform and precoding design for coexistence of MIMO radar and MU-MISO communication", consider the design of the radar transmit waveform, receive filter and communication precoding matrix for coexistence of the MIMO radar and multi-user multiple-input-single-output (MU-MISO) communication systems. The design is achieved by maximising the radar SINR and the minimal SINR of communication users, simultaneously, which is different from the conventional design schemes that require defining the primary function. By doing so, the overall performance for both sensing and communication is achieved without requiring parameter tuning for the threshold of communication or radar. To solve the highly non-convex optimization problem which contains the maximin objective function, the epigraph-form reformulation is first adopted, and then an alternating maximisation (AM) method is devised, in which the Dinkelbach's algorithm is used to tackle the non-convex fractional-programing subproblem. Simulation results indicate that this method can achieve improved performance compared with the benchmarks.

He and Huang, in their paper "Transceiver coexistence design of MIMO radar and MIMO communication under-Gaussian model uncertainty", proposes a transceiver coexistence design of MIMO radar and MIMO communication under-Gaussian model uncertainty. Specifically, Gaussian uncertainties in the radar system and communication system are modelled, and robust transceivers for radar and communication systems are obtained with probabilistically guaranteed quality of service (QoS) in terms of SINR, effective SINR (ESINR)and mean square error (MSE). Moreover, instead of the communication QoS criteria in terms of channel capacity and SINR, the symbol detection MSE is taken as the QoS criterion in this paper. Owing to the MSE formulation, the convex relaxation of the communication transmitter is proved to be tight. Extensive simulation results show that when the proposed iterative algorithm converges, the possible radar rank-one relaxation error is trivial with respect to the numeric error, and the QoS in terms of SINR, ESINR, MSE and bit error rate (BER) in the proposed coexistence system are robust against model uncertainty with the cost of using extra transmit power.

Su *et al.*, in their paper "Communication-awareness adaptive resource scheduling strategy for multiple target tracking in multiple radar system", present a communication-aware adaptive resource scheduling (CARS) strategy for multiple target tracking (MTT) in multiple radar system (MRS). The CARS strategy aims to maximise the tracking performance of MRS, whilst minimising the interference from MRS to communication systems (CSs), whose mechanism is to simultaneously control the revisit frame interval of each target and determine the activation of radar nodes, the radar-target assignment and the allocation of the transmitted power. The CARS strategy is formulated as an optimization problem, which contains both the continuous variable and the discrete (integer) variable. By making use of the hybrid particle swarm optimization (HPSO) algorithm based on the Kullback-Leibler divergence (KLD), a two-stage solution technique is developed to tackle the resultant mixed-integer, non-convex, and non-linear problem. Numerical simulation results are provided to validate the proposed CARS strategy and demonstrate its superiority over the traditional scheduling strategies.

2 | BEAMFORMING FOR RADAR AND COMMUNICATION

Kaushik et al., in their paper "Towards 6G: spectrally efficient joint radar and communication with RF selection, interference and hardware impairments", present a spectrally efficient method for MIMO joint radar-communication (JRC) system with hybrid beamforming architecture and multi-antenna setup while considering the interference between communication and radar operations, and hardware impairments in the system. This method selects the optimal number of RF chains while the impact of communication/radar interference and hardware impairments is taken into account. It outperforms the baseline methods both in terms of communication and radar rate values with respect to variations in different signalling and system parameters. Numerical results show that the proposed method with radar interference and hardware impairments achieves high spectral efficiency when compared with the existing fully digital and hybrid beamforming method with a fixed number of RF chains. A favourable communication and radar trade-off in terms of spectral efficiency gains is observed within the proposed approach.

Xiao et al., in their paper "Hybrid beamforming design for OFDM dual-function radar-communication system with optimised transmit beampattern", investigate the problem of hybrid beamforming design in orthogonal frequency division multiplexing (OFDM) dual-function radar-communication (DFRC) system to achieve an optimised transmit beampattern subject to the constraints of communication performance and transmit power. Specifically, the analog beamformer and digital beamformer for each subcarrier at the transmitter are designed by maximising the integrated mainlobe-to-sidelobe ratio (IMSR) of the transmit beampattern under the restriction of communication SINR. In order to solve the complex multi-constraint problem, firstly, the objective function with fractional programing is converted by a quadratic transform technique, then the communication SINR is simplified and approximated by the first-order Taylor expansion. Finally, the problem is tackled under the framework of C-ADMM. The effectiveness of the proposed design is verified by simulation results.

Shi et al., in their paper "Transmitter and receiver design for integrated full-duplex MIMO communication and MIMO radar system", discuss the integrated system of full duplex (FD) MIMO communication and MIMO radar. This is composed of a base station and several uplink (UL) and downlink (DL) users. Further, the system is supposed to simultaneously implement three functionalities, that is, target detection, UL and DL communications. The transmit and receive beamformers are designed by maximising a compound communication sum-rate metric, subject to the SINR constraint imposed on target detection performance. To tackle the resulting non-convex optimization problem, an iterative algorithm is developed with the aid of fractional programing (FP) and consensus alternating direction method of multipliers (C-ADMM) algorithm. The convergence performance and computational efficiency of the proposed algorithm are illustrated by simulations.

Gong *et al.*, in their paper "FDA-MIMO radar transmit beamforming design for LPI in cluttered environments", investigate the transmit beamforming matrix optimization for Low-Probability of-Intercept (LPI) of multiple-input multiple-output with frequency diverse array (FDA-MIMO) radar, which can accurately control the transmit beam energy to meet the LPI requirements and the clutter suppression. The transmit beamforming matrix is designed along with the receive filter to maximise the receive output SINR under the power constraint to suppress the clutter and interference signals, while minimising the radiated power at the target to reduce the radar interception probability. The resulting problem is tackled by using quadratic transformation and ADMM algorithm. Simulation results show that the proposed method can achieve the desired transmit beampatterns.

3 | TARGET DETECTION AND PARAMETER ESTIMATION FOR RADAR AND COMMUNICATION

Wang and He, in their paper "Quantization-based target detection for cooperative MIMO radar and communications with multiple stations", study the target detection for the case where multiple radar and communication stations are physically separated, possibly widely spaced, while working in a cooperative way. To utilise all available information for final decision making, the radar stations that receive signals send their local measurements to a fusion centre (FC) through a backhaul network. To reduce communication traffic, the local measurements are quantized and then transferred to the FC. Three strategies for the quantization and fusion are considered, where, for the first method local sensors quantise their test statistics which are linearly fused at the FC (QTLF), for the second method the test statistics are quantized at the local sensors and optimally fused at the FC (QTOF), and for the third method the received signals are quantized at the local sensors and optimally fused at the FC (QROF). The detection probability for each method is derived for the cooperative IRC system and compared with the non-cooperative counterpart. It is proved that there is a detection performance gain through cooperation between the radar and communication systems and the cooperative IRC system can achieve the same performance as the non-cooperative system with less quantization bits. The theoretical analysis is verified by simulations.

Zhu *et al.*, in their paper "An efficient target detection algorithm via Karhunen-Loève transform for FMCW radar applications", investigate an advanced effective signal processing technique for noise suppression and high-performance detection in radar sensing. The frequency modulated continuous wave (FMCW) radar is taken as a case study to derive the algorithm based on the Karhunen-Loève transform (KLT) before detection. The performance of the algorithm is evaluated by different eigenvalue selection strategies. Numerical experiments are employed to obtain the relationship between signal-to-noise ratio (SNR) and different eigenvalue selection strategies. The constant false alarm ratio (CFAR) detector is applied to demonstrate the detection ability as a result of the processor by use of probability of detection.

Wang et al., in their paper "Transmitter selection and receiver placement for target parameter estimation in cooperative radar-communications system", consider target parameter estimation for the cooperative MIMO radar and MIMO communications system. To address the hardware limitation of the radar system, a joint transmitter selection and receiver placement (JTSRP) problem is formulated to minimise the estimation performance benchmarked by the Cramer-Rao bound (CRB), where the transmitters can be selected from a discrete set and the receivers can be deployed over a continuous region. The resulting mix-integer nonlinear programing problem is approximately solved by a genetic algorithm (GA)-based method. It is shown that the result obtained by the proposed algorithm is close enough to the optimum solution of the JTSRP problem.

4 | WAVEFORM DESIGN FOR RADAR AND COMMUNICATION

Xiao et al., in their paper "OFDM integrated waveform design for joint radar and communication", present several OFDM-based waveform design approaches for JCR systems. Compared with the existing methods only considering the sidelobe suppression of the integrated waveform, some feasible schemes to achieve superior performance in terms of data rate and ambiguity function are investigated, including the iterative optimization of the peak sidelobe ratio (PSLR) and the peak to average power ratio (PAPR) to improve the range resolution without degrading Doppler resolution. In order to efficiently implement the subsequent radar processing and estimate the joint range-velocity profile in radar detection, the corresponding algorithm to retrieve the modulated information of the communication is presented, resulting in more degrees of freedom (DOFs) to estimate the related radar parameters in temporal, spectral and spatial domains. Meanwhile, potential benefits of the proposed OFDM waveform combined with the MIMO technique are analysed. Theoretical analysis and simulation results verify the effectiveness of the designed integrated waveform.

Wan *et al.*, in their paper "Transmit waveform and receive filter design for MIMO Radar with one-bit DACs", investigate the joint design of transmit waveform and receive filter for collocated MIMO radar equipped with one-bit digital-to-analog converters (DACs). The problem is formulated as maximising the output SINR in the presence of signal-dependent interferences, subject to a discrete constraint imposed by the waveform quantized with one-bit DACs. A sequential alternating maximisation (AM)-based algorithm is developed to cope with the resulting non-convex problem. Specifically, it is firstly shown that the receive filter can be analytically obtained when the signal waveform vector is given. Then, a biconvex relaxation (BCR)-based algorithm is devised to solve the optimization problem with respect to the signal waveform vector for a given receive filter vector. Numerical simulations in different circumstances were carried out to demonstrate the performance of this approach.

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