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A New Approach for Radar/SAR target Detection and Imagery Based on MIMO System Concept and Adaptive Space-Time Coding

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Abstract

A new adaptive and distributed SAR (Synthetic Aperture Radar) concept for recognition and imaging of targets with fading, varying and unstable signatures in a complex environment is explored. These targets (e.g., moving targets, targets in presence of strong, variant and potentially intelligent interference) represent an important class of military ATR applications within the complex urban environment that cannot be effectively handled by current SAR systems and techniques. The MIMO (multiple-input multiple-output) approach taken for accurate modeling of the radar system channels provides effective adaptivity for optimal radar mode selection and signal processing and, can handle target radar cross section (RCS) fading and scintillations within the illumination interval. In particular, the proposed MIMO SAR system can exploit the RCS variations to improve the performance by virtue of the incoherent processing and its multistatic nature. The present approach also characterizes a radar system as a wireless communications system to which useful metrics and methods for overall system optimization apply and provides compatibility for integration into a hybrid network.

Résumé

On étudie un nouveau concept de SAR (radar à synthèse d’ouverture) adaptatif et distribué pour la reconnaissance et l’imagerie de cibles dont les signatures s’affaiblissent, varient ou sont instables dans un environnement complexe. Ces cibles (p. ex. cibles mobiles, cibles en présence de brouillage fort, variable et éventuellement intelligent) représentent une classe importante d’applications militaires de reconnaissance automatique des cibles (ATR) dans l’environnement urbain complexe qui ne peuvent pas être traitées efficacement par les systèmes et les techniques SAR actuels. L’approche MIMO (entrées multiples, sorties multiples) adoptée pour la modélisation précise des canaux de système radar permet une adaptivité efficace pour la sélection du mode radar optimal et le traitement optimal des signaux, et elle permet de gérer l’affaiblissement de la surface équivalente radar (RCS) et les scintillations de la cible dans l’intervalle d’illumination. En particulier, le système SAR MIMO proposé, en raison du traitement incohérent et de sa nature multistatique, peut exploiter les variations de la RCS pour accroître l’efficacité. La présente approche caractérise également un système radar comme étant un système de communications sans fil auquel s’appliquent des paramètres et des méthodes utiles pour l’optimisation du système entier et elle offre la compatibilité nécessaire pour l’intégration à un réseau hybride.

Executive summary

A new distributed and adaptive SAR concept capable of recognizing difficult targets in a complex environment is explored in this work. A MIMO approach is adopted and developed for accurate modeling of the radar system channels, and, the incorporation of those channels knowledge into design of optimal radar's mode of operation and data exploitation algorithms. According to radar and communication theories, such systems can offer reliable performance under fading target or channel conditions by applying MIMO space-time techniques. Effective operation under fading conditions due to factors like target scintillation, motion, varying clutter and environmental conditions is the unique strength of the proposed radar system. This capability, which is not offered by current SAR systems, introduces a new class of airborne/spaceborne adaptive radars ideal for advanced ATR in urban environments.

The proposed MIMO SAR adaptive radar would provide the capability to detect and recognize fading, moving and interfered (naturally or by design) targets in non-cooperative and complex environments. One typical application is the detection and recognition of difficult targets in complex urban environments that represent current and future threats. Reliable and timely detection of such threats is an important factor that is addressed in the present radar system by virtue of its highly adaptive nature and potential for network-enabled operation. The possibility of network-based operation provides the real time functionality.

This work also explores and models distributed radar sensors as communications nodes providing the infrastructure for network enabled operations. Such a radar network will not only provide optimal and accurate detection according to the MIMO theory, it also establishes the ground for integration of different sensors and systems in a hybrid network. The outcome will contribute to interoperability of different sensors, convergence of military Comms and radars, and ultimately the integrated Canadian Forces vision.

This study and future related works will contribute to the development of future capabilities for complex and urban operations, and throughout its course, will contribute to the development of new competencies in areas such as MIMO-based adaptive and distributed surface and spaceborne/airborne radar systems within DRDC.

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Sommaire

Dans le cadre de ce travail, on étudie un nouveau concept de SAR distribué et adaptatif permettant de reconnaître des cibles difficiles dans un environnement complexe. Une approche MIMO est adoptée et développée pour la modélisation précise des canaux de système radar et pour l'incorporation des connaissances relatives à ces canaux à la conception d'un mode optimal d'exploitation du radar et d'algorithmes d'exploitation des données. D'après les théories du radar et des communications, on peut se fier à ces systèmes dans des conditions d'affaiblissement de cible ou de canal en appliquant des techniques espace-temps MIMO. Le fonctionnement efficace dans des conditions d'affaiblissement, résultant de facteurs tels que la scintillation des cibles, le mouvement, les changements en ce qui concerne le clutter et le milieu ambiant, constitue la force unique du système radar proposé. Cette capacité, que ne possèdent pas les systèmes SAR actuels, fait apparaître une nouvelle classe de radars adaptatifs aéroportés/spatiaux idéaux pour la reconnaissance automatique des cibles (ATR) avancée dans les environnements urbains.

Le radar adaptatif SAR MIMO proposé permettrait de détecter et de reconnaître des cibles dont les signaux s'affaiblissent, qui sont mobiles ou qui subissent un brouillage (naturel ou intentionnel) dans des environnements non coopératifs et complexes. Une application type consiste en la détection et la reconnaissance de cibles difficiles dans des environnements urbains complexes qui représentent des menaces actuelles et futures. La détection fiable et en temps opportun de ces menaces constitue un facteur important qui est pris en compte dans le présent système radar en raison de sa nature hautement adaptative et de ses possibilités d'exploitation facilitée par réseau. La possibilité d'exploitation facilitée par réseau assure la fonctionnalité en temps réel.

De plus, ce travail étudie et modélise l'utilisation de capteurs radar distribués en tant que nœuds de communications fournissant l'infrastructure pour les opérations facilitées par réseau. En plus de permettre la détection optimale et précise d'après la théorie MIMO, un tel réseau de radars permet d'établir la base pour l'intégration de différents capteurs et systèmes dans un réseau hybride. Le résultat contribuera à l'interopérabilité de différents capteurs, à la convergence des communications et des radars militaires, et en bout de ligne à la vision des Forces canadiennes intégrées.

Cette étude et les recherches futures connexes contribueront au développement de capacités futures pour les opérations complexes et urbaines, et, tout au long de leur réalisation, contribueront au développement de nouvelles compétences dans des secteurs comme celui des systèmes de radars de surface et de radars spatiaux/aéroportés adaptatifs et distribués basés sur la technologie MIMO, au sein de RDDC.

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1. Introduction

1.1 Preamble

Study of radar principles and a parallel investigation of those aspects in the context of communication theory [1]-[2] reveal that an optimal radar performance can be achieved through judicious design of radar transmitter and receiver configuration, and application of efficient signal processing schemes for both transmit and receive waveforms. These requirements, to some extent, are addressed in array or distributed radar systems [3] and techniques [4]-[7]. Techniques for data exploitation and signal processing (mostly coherent based) applied to array radar systems range from high resolution techniques like space-time filtering (data independent or adaptive [8]) and maximum likelihood (ML) [9], to beamforming techniques similar to directional antenna radars [3].

Any radar system is analogous to a complex wireless communication system with, in general, a space-time varying multi-channel structure. In a radar scenario, paths connecting transmitter points to scatterer points, scatterer inputs to outputs, scatterer points to receiver points, or any combination thereof (i.e., transmitter points to receiver) constitute radar channels. Thus, one may technically adopt appropriate multipath wireless communication system solutions and techniques (upon proper radar channel modeling) to enhance the performance of a radar system. Such wireless systems performance optimization in a fading environment using space-time techniques (e.g., space-time coding) are well researched and at a relatively advanced state [2], [10]. There have been recent novel proposals on statistical MIMO radars from Bell Labs [11] with very promising results. There are also excellent examples of bistatic and passive radars, passive coherent radars (PCR) and passive coherent locators (PCL) that take advantage of similar principles. These systems that are rapidly growing interest and functionality [12]-[13], may not be optimally exploited due to the lack of a comprehensive system model, and hence, an effective adaptive operation. Application of advanced space-time techniques will open a new chapter for airborne and spaceborne radar operation and effective data exploitation.

SAR provides target recognition, resolution and imaging capability by the virtue of coherent processing gain. SAR system performance is degraded if the coherent assumptions are violated and if channel fading occurs within the synthetic aperture illumination region. SAR theory and techniques at current state, cannot effectively handle recognition and imaging of targets with fading, varying and unstable signatures. Nevertheless, these targets (e.g., moving targets, targets in complex and non-cooperative environments, targets in presence of strong, variant and potentially intelligent interference) represent an important class of military ATR applications dealing with asymmetric and time sensitive threats.

Deficiency of current SAR systems and exploitation techniques in dealing with difficult targets may be attributed to a number of key factors: 1) Lack of optimally rigorous modeling for radar EM phenomenon characterization and respective data exploitation; which is not properly incorporated (due to its complexity) even in space-time adaptive processing (STAP) techniques, 2) Non-adaptive radar mode selection; adaptivity is currently offered in the processing end of radar operation, thus, if the radar channel associated with a target is fading, STAP and beamforming techniques can not provide reliable detection and recognition, 3) Dependence on coherent and/or high-correlation based signal processing. STAP, beamforming and array processing are coherent SAR processing techniques and are significantly degraded if target radar cross section (RCS) fading, fluctuations or scintillations were considerable within the illumination interval due to the resultant decorrelation between signals received by an array. Experimental results and theoretical results [1], [14] show that scintillations of more than 10 dB may be experienced for a small (milliradian) change in aspect angle.

Here, we identify the challenge as reliable detection and recognition of targets with fading, varying or unstable signatures due to the target motion, natural or manmade interference or environmental conditions. A good example of such scenario is the ATR for detecting fading and difficult targets in complex urban environments.

1.2 Motivations

Targets in an urban environment represent fading and time varying signatures as the result of movement, interference (e.g., shadowing), correlation with the complex clutter and multipath effects. Due to the sophisticated nature of these effects, target signal recovery, reconstruction and associated imagery exploitation become considerably difficult using the current and conventional SAR techniques. The current SAR imagery, even using adaptive processing techniques, may not (can not) reveal the true target nature since characteristic target profile/signature could be virtually non-existent through the applied mode of operation. Furthermore, different modes of operation (e.g., incident and scattering angles, frequency) would highlight different and diverse targets features as the result of channel response variations, and not necessarily, the target scattering response. Evidence for such is the observed point source or point spread function (side lobes and tails behavior in particular) for certain target and clutter types. Accordingly, if knowledge of overall channel variations is not properly incorporated, target exploitation yields erroneous results as such variations would be attributed to a particular target scattering mechanism. Thus, new SAR systems, processes and methodologies are needed to accurately incorporate comprehensive channel information for advanced target recognition and detection. This complete channel description will be used to identify and optimize the operational mode. As well, it will be used to identify the target characteristic signatures under the assumed channel conditions hence enhancing the classification/recognition and avoiding misinterpretation.

The core component of these new systems and processes is the overall channel model that is space-time varying and vectorial by nature. This model is established through a thorough formulation of electromagnetic phenomenon (from propagation to scattering). The acquired knowledge will be used to design and optimize the desired operational modes and respective signal processing schemes.

2. MIMO SAR Concept

A generalized spaceborne or airborne SAR scenario represents a complex array system with both physical and synthetic array elements. The goal here is to research and develop the concept and potential design of a new adaptive and distributed SAR based on MIMO theory and techniques. Adopting a MIMO approach, the adaptive SAR system will be modeled as a "spatio-tempora-polar multiple-input multiple-output (MIMO)" communications channel. The MIMO SAR system and associated exploitation methodology will address the shortcomings of current systems described earlier for the intended applications. First, accurate formulation and characterization of EM phenomenon will serve as a solid tool to describe the radar channels. This knowledge will be effectively used to design optimal SAR configuration and adaptive processing algorithms. Since in a MIMO scenario, targets may be observed through different paths or channels by a distributed system, applying the channel knowledge can also identify an optimal radar mode of operation. This mode will be realized by designing space-time transmit codes, hence providing adaptivity for radar mode selection. The MIMO concept can handle target RCS fading, scintillations and glint (i.e., decorrelation of received signals by an array) by virtue of the incoherent processing gain due to its multistatic nature. In fact, the MIMO system will capitalize the RCS spread to improve the performance and distinguishing the target due to multi-aspect view of the target.

MIMO SAR concept combines the EM remote sensing aspect of SAR to its communications system profile to which communication channel metrics and measurables, e.g., spectral efficiency, space-time coding, and associated optimization techniques apply. It also provides the possibility of systematic integration within a communication network for network-enabled operations.

The objective for the future work based on the current study is to: (1) Evaluate the feasibility of a MIMO SAR scheme for enhanced target recognition and imaging using available SAR data; Develop an accurate MIMO equivalent model via: (2) Multipath propagation channel modeling between scatterer and receiver or transmitter, (3) Channel modeling of the scatterer or scattering for cascading to the propagation matrix; (4) Investigate new adaptive processing schemes based on the knowledge of (2)-(3); (5) Devise array configuration using (2)-(4) and implement it; (6) Investigate, develop and apply space-time codes to enhance performance; and (7) Explore the possibility of exploiting the correlation between transmit codes and target classes for target classifications. Achievement of these objectives will provide support for advanced and automatic target recognition (ATR) tasks in complex environments.

We may quantify the approach to achieve the described objectives as:

(1) Characteristic definition and development of MIMO model for polarimetric SAR and evaluation of radar channels using available airborne data.
(2) Electromagnetic modeling of multipath space-time varying radar channels.
(3) Electromagnetic modeling of the scatterer channels (incident to scattered matrix).
(4) Use of space-time coded transmit waveforms to investigate channel interaction with different codes for known scatterers.

(5) Design proper transmit code structure for different classes of scatterers (e.g., stationary or moving targets).
(6) Utilization of new synthetic and/or physical array configurations and application of coherent, non-coherent, and/or hybrid (coherent/incoherent) processing schemes.
(7) Design and conduct controlled and real target experiments to verify and demonstrate theoretical model and/or extract parameters of interest.

3. Technical Methodology

As described, the desired research objectives require an elaborate and well-defined research plan and methodology due to the multifaceted nature. To address this, three major categories or steps are identified.

3.1 Fundamental Electromagnetic Formalism and Communication System Modeling

1. Define and elaborate a comprehensive equivalent MIMO model for a general polarimetric airborne/spaceborne SAR.
2. Develop a general SAR polarimetric space-time channel model using various techniques based on EM theory, and compare with numerical models and available experimental data to verify and tune the model.
3. Develop target scattering channel model or operator/matrix using EM scattering methods for various targets and target classes of interest, and compare with numerical models and available experimental data to verify and tune the model.

At this stage, a comprehensive spatio-tempora-polar MIMO model (basis for an analytic simulator) representing a general multistatic SAR scenario would be available that connects radar transmit points to its receive points. Hence, a wireless communications channel version (multipath) of the radar would be provided for further system considerations (e.g., optimization, coding).

3.2 Algorithm Development, Computer Simulation, MIMO SAR Development and Analysis

1. Develop algorithm and perform computer simulation to investigate channel behavior, selectivity, multipath effects and fading.
2. Develop algorithm and perform computer simulation to investigate multistatic scattering for different targets and classes of targets.
3. Develop MIMO channel simulator to analytically describe any communications channel in the system, i.e., transmitter points to receiver points.
4. Devise, design and optimize the processing algorithm for given radar configuration and desired application.
5. Design and implement novel array system architectures and develop space-time coding schemes to optimize the system operation.
6. Explore feasibility of establishing a systematic relation between the transmit space-time codes and targets for a new target classification strategy.

At this stage, the theoretical and software tools would be available to optimize the radar system and efficiency, explore various configurations and target identification schemes.

3.3 Designed and real target experimentations

1. Design and conduct controlled experiments to measure and verify/modify the MIMO channel characteristics using known calibration targets.
2. Design and conduct controlled experiments to measure and verify/modify the target scattering channel characteristics for targets of interest.
3. Conduct experiments using different codes for various classes of targets to investigate and demonstrate how, and to what extent, a proper combination of different coding and processing schemes can distinguish different scatterers or targets identities, i.e., target classification efficiency.

4. Theory

4.1 EM & MIMO Formalism

The core theoretical formalism deals with the EM modeling of general propagation and scattering, and development of comprehensive channel models from EM wave transmitters to receivers. A general scenario schematic is depicted in Figure 1.

Assuming a general scenario, the received vector or polarimetric waveform may be written as:

$$\mathbf{E}_{rec}(t,\mathbf{v}) = \int d\mathbf{x}\, G(t,\mathbf{v}-\mathbf{x}) \left\{ \overleftrightarrow{\mathbf{S}}(t,\mathbf{x},\mathbf{v}).\left[\mathbf{E}_{trans}(\mathbf{x}) * G(t,\mathbf{x})\right]\right\} \tag{1}$$

where $G(t,\mathbf{r}), \overleftrightarrow{\mathbf{S}}(t,\mathbf{x},\mathbf{v}), \mathbf{E}_{trans}(\mathbf{x})$ are the general time-varying propagation Green's function, target scattering operator (sensor/aperture dependent) and transmitted vector waveform (in time spectral domain), respectively. In (1), symbol $'*'$ denotes the space-domain (invariant) convolution.

Thus,

$$\begin{aligned}\mathbf{E}_{rec}(t,\mathbf{v}) &= \iint d\mathbf{x}\, d\mathbf{u}\, G(t,\mathbf{v}-\mathbf{x})\, G(t,\mathbf{x}-\mathbf{u})\, \overleftrightarrow{\mathbf{S}}(t,\mathbf{x},\mathbf{v}).\mathbf{E}_{trans}(\mathbf{u}) \\ &= \int d\mathbf{u}\, \overleftrightarrow{\mathbf{T}}(t,\mathbf{v},\mathbf{u}).\mathbf{E}_{trans}(\mathbf{u})\end{aligned} \tag{2}$$

where

$$\overleftrightarrow{\mathbf{T}}(t,\mathbf{v},\mathbf{u}) = \int d\mathbf{x}\, G(t,\mathbf{v}-\mathbf{x})\, G(t,\mathbf{x}-\mathbf{u})\, \overleftrightarrow{\mathbf{S}}(t,\mathbf{x},\mathbf{v}) \tag{3}$$

Equations (1)-(3) provide analytic means to describe the MIMO structure of a distributed radar system in terms of input and output wave vectors defined at general space-time coordinates $(t,\mathbf{u})$ and $(t,\mathbf{v})$. Here we introduce the MIMO dyadic time-varying channel response as:

$$\overleftrightarrow{H}_{vu}(t) \triangleq \overleftrightarrow{\mathbf{T}}(t,\mathbf{v},\mathbf{u}) \tag{4}$$

where u, v indices refer to multi-channel transmitting and receiving nodes or points $\mathbf{u}, \mathbf{v}$. The dyadic property of channel response function indicates the vectorial nature of the transmit/receive electromagnetic signals. This is an important aspect included in the channel model that is beneficial to advanced radar and SAR target recognition applications (e.g., polarimetric). Thus, the system equations can be written as:

$$\mathbf{Y}_v(t) = \sum_u \overleftrightarrow{H}_{vu}(t).\mathbf{X}_u \tag{5}$$

where $\mathbf{X}_u$ and $\mathbf{Y}_v(t)$ EM waveforms or field signals represent the transmitted and received vector EM code segments or code vector components, and symbol '.' denotes the conventional inner product. The time-dependence notation assumed for the received signal (as opposed to the transmitted signal) represents the overall time-varying channel effects.

Equally in a matrix form:

$$\left[\vec{\mathbf{Y}}(t)\right] = \left[\overleftrightarrow{H}_{vu}(t)\right].\left[\vec{\mathbf{X}}\right] \tag{6}$$

Matrices $\left[\vec{\mathbf{X}}\right]$ and $\left[\vec{\mathbf{Y}}(t)\right]$ in (6) are the transmitted (time spectral from $u = 1..U$ points) and received EM codes (at $v = 1..V$ points) as given by:

$$\left[\vec{\mathbf{X}}\right] = \begin{bmatrix} \mathbf{X}_1 \\ . \\ . \\ \mathbf{X}_U \end{bmatrix} \tag{7}$$

$$\left[\vec{\mathbf{Y}}(t)\right] = \begin{bmatrix} \mathbf{Y}_1(t) \\ . \\ . \\ \mathbf{Y}_V(t) \end{bmatrix} \tag{8}$$

or, in general, they represent input and output EM code words as:

$$\left[\vec{\mathbf{X}}\right] = \begin{bmatrix} \mathbf{X}_1^{(1)} & . & . & \mathbf{X}_1^{(K)} \\ . & . & . & . \\ . & . & . & . \\ \mathbf{X}_U^{(1)} & . & . & \mathbf{X}_U^{(K)} \end{bmatrix} \tag{9}$$

$$\left[\vec{\mathbf{Y}}(t)\right]=\begin{bmatrix}\mathbf{Y}_1^{(1)}(t) & . & . & \mathbf{Y}_1^{(K)}(t)\\ . & . & . & .\\ . & . & . & .\\ \mathbf{Y}_V^{(1)}(t) & . & . & \mathbf{Y}_V^{(K)}(t)\end{bmatrix} \tag{10}$$

with K and U indicating the coded signal number and code length.

As an example, consider a single code $\left[\tilde{\mathbf{s}}_1 \quad \tilde{\mathbf{s}}_2 \quad ... \quad \tilde{\mathbf{s}}_U\right]$ transmitted from U transmit points and received at a receive point $R \in [1...V]$. The received EM signal becomes:

$$\mathbf{Y}_R(t)=\sum_{i=1..U}\overleftrightarrow{H}_{Ri}(t).\tilde{\mathbf{s}}_i \tag{11}$$

Adopting a matrix convention, each channel transfer function component or operator $\overleftrightarrow{H}_{ij}(t)$ may be presented by a square matrix:

$$\overleftrightarrow{H}_{ij}(t)=\begin{bmatrix}........\\ ....\\ ....\end{bmatrix}_{n\times n} \tag{12}$$

where n indicates dimension of the polarization space, i.e., $n=2$ for two dimensional and $n=3$ for three dimensional EM signal decomposition. In order to simulate a typical SAR scenario (single channel, i.e., $n=1$), one can assume a uniform (or normalized) single code:

$$\vec{X}=\begin{bmatrix}1 & 1 & ... & 1\end{bmatrix}_M \tag{13}$$

where M indicates the number of profiles or slow-time pulses. This is given by pulse repetition frequency (PRF) and image acquisition time (T) product,

$$M=T.PRF \tag{14}$$

Adopting the conventional SAR channel invariance assumption and using (2)-(4), we can express the complete channel transfer function as:

$$H_{ij}=\delta_{ij}\,\frac{\exp(-jk\left|\mathbf{v}_i-\mathbf{x}\right|-jk\left|\mathbf{v}_j-\mathbf{x}\right|)}{\left|\mathbf{v}_i-\mathbf{x}\right|.\left|\mathbf{v}_j-\mathbf{x}\right|}S(\mathbf{x})=\delta_{ij}\,\frac{\exp(-j2k\left|\mathbf{v}_j-\mathbf{x}\right|)}{\left|\mathbf{v}_j-\mathbf{x}\right|^2}S(\mathbf{x}) \tag{15}$$

where $\mathbf{v}_j$ denotes the location of receiver (and transmitter) nodes for monostatic SAR operations. In (15), $\mathbf{x}$ and $S(\mathbf{x})$ represent location and scattering coefficient or reflectivity of the target. Also,

$$\delta_{ij} = \begin{cases} 0 \, , \, i \neq j \\ 1 \, , \, i = j \end{cases} \tag{16}$$

is the Kronecker delta.

A simplified version of the transfer function in (15) represents the conventional SAR processing kernel. Examination of (15) and associated simplifying assumptions, as compared to the general form (3)-(4), reveals the amount of information that is not incorporated in processing and subsequent exploitations. The noted simplifications are mainly related to amplitude variations, possible transport channel dispersion and nonlinearity, and synthetic aperture dependence of scattering or target reflectivity.

4.2 System Model

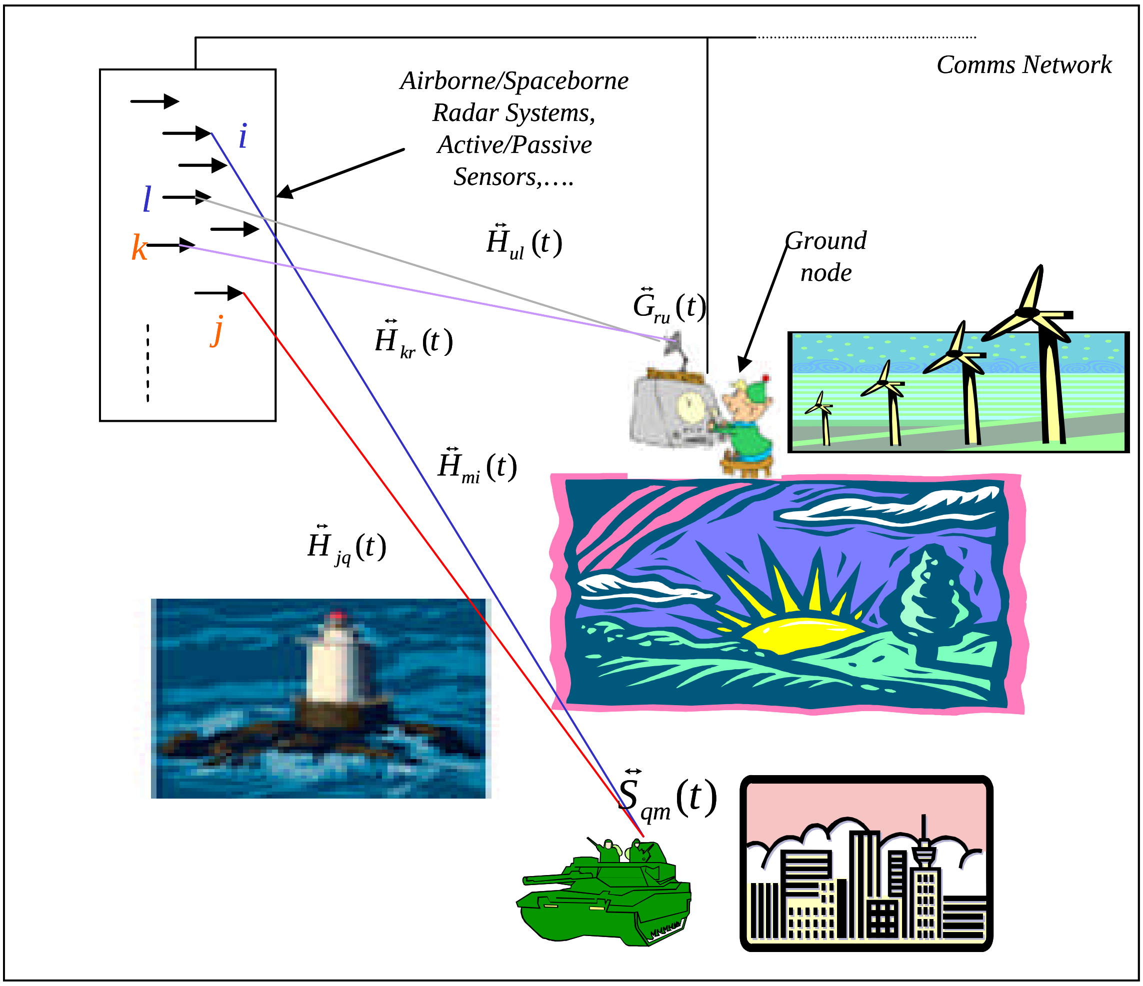
The detailed formalism constitutes the framework for modeling and emulating a complex and hybrid radar/SAR system. The overall system model is established by determining each component through analytical derivations, empirical techniques, measurements, experimentations, and/or, a combination of such. For instance, the propagation channel model may be established by measuring the channel response coefficients associated with the assumed analytic model, e.g., channel sounding. Conveniently, the channel measurements and/or sounding may be performed using a combination of different sensors of opportunity (e.g., telecom) or tactical necessity (e.g., silent, passive sensors).

The proposed MIMO system modeling and processing architecture is depicted in Figure 2. As can be seen, upon building and tuning (ongoing process for applications of interest) various code sets are optimized to yield desired operational outcome. The overall processing flow, evaluation and optimization is controlled by a central or core unit that constantly monitors the MIMO system characteristics, determines and utilizes the optimum channel-signal (or code) configuration. Evidently, the described core unit is in continuous interaction with an exploitation core to import the requirements and export various products. Also, this core unit is connected to a communications system or network backbone.

There are certain distinctive features associated with the current scenario. As addressed before, various sensor nodes may be utilized to create the dynamic channel model and to determine the optimal codes or mode of operation. The associated channels can also be used to transfer partial or supplementary target information. For instance, certain narrow-bandwidth features of a target or scatterer (illuminated by a radar or non-radar source) may be detected by a passive sensor and be fused to other radar/SAR products to enhance exploitation, e.g., detection, recognition, image quality.

Another feature is the modularity of the modeling and evaluating blocks that offers parallel utilization and optimization.

In addition to the diverse product processing capability for exploitation, the proposed MIMO system or configuration provides (by nature) comprehensive signal information and analysis along with the generated product (e.g., imagery). Such complementary information and knowledge is invaluable for advanced radar/SAR data exploitations.

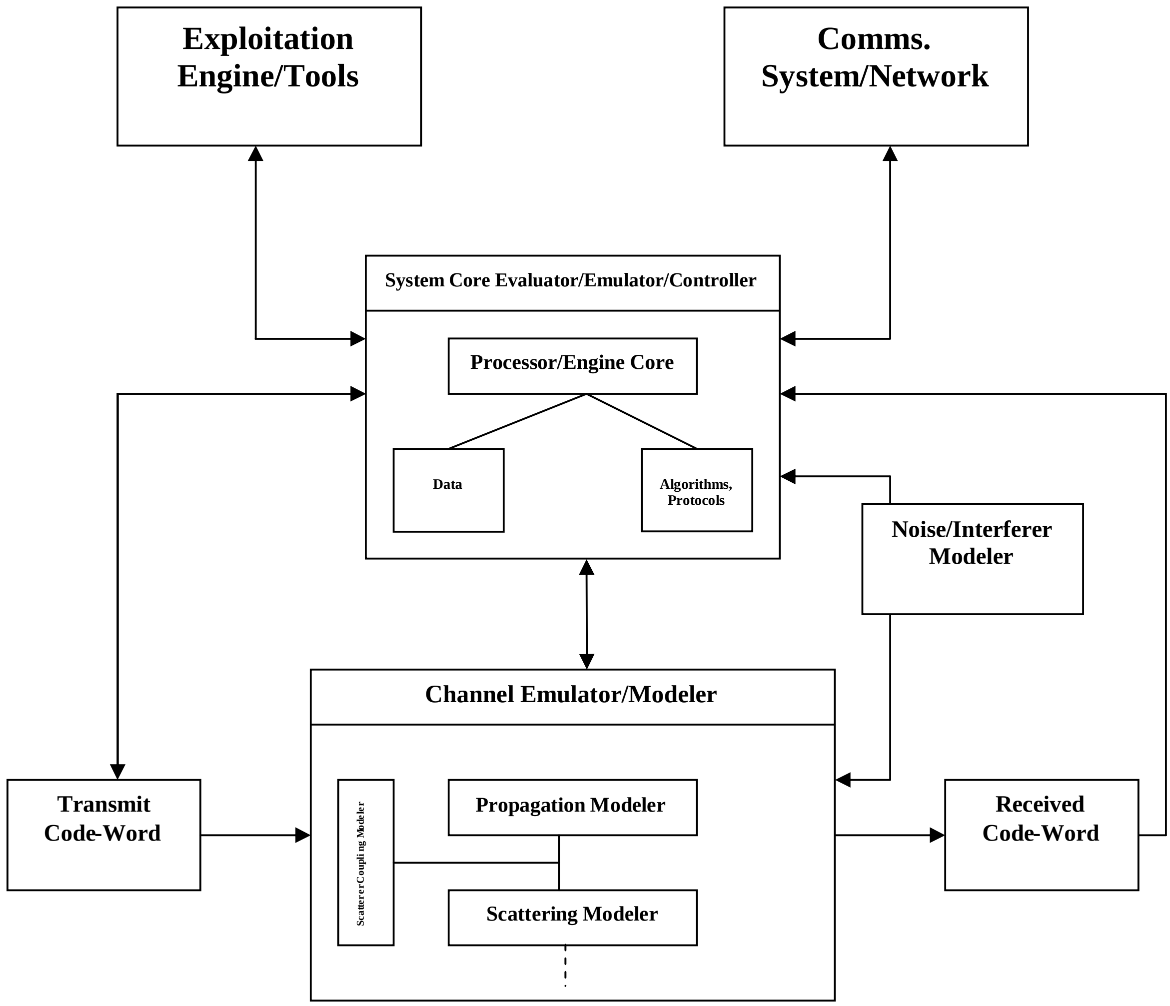


$$\overleftrightarrow{H}_{ji}(t) = \overleftrightarrow{H}_{jq}(t) \otimes \overleftrightarrow{S} \otimes \overleftrightarrow{H}_{mi}(t)$$

$$\overleftrightarrow{H}_{kl}(t) = \overleftrightarrow{H}_{kr}(t) \otimes \overleftrightarrow{G} \otimes \overleftrightarrow{H}_{ul}(t)$$

Figure 1: General Radar MIMO System Schematic

Figure 2: Overall Radar/SAR MIMO System Structure; Modeling and Processing Flow Diagram



5. Concluding Remarks

The research proposed here introduces a fundamental first step in developing a new generation of surveillance radars capable of operating in complex environments and conditions. Operations in an urban environment with non-stationary radar returns due to target motions, target fading, varying clutter and weather conditions are examples of those potentials and capabilities. Considering the distributed nature of radar in this proposal, the move towards establishing a robust surveillance platform is also explored that will ultimately provide the military and related agencies with the required intelligence to perform precise and tailored operations under complex circumstances.

A new distributed and adaptive SAR concept capable of recognizing difficult targets in a complex environment is explored. Adopting a MIMO approach, radar system channels are modeled, and, those channels knowledge are incorporated into design of optimal radar's mode of operation and data exploitation algorithms. According to radar and communication theories, such system can offer reliable performance under fading target or channel conditions by applying MIMO space-time techniques. Effective operation under fading conditions due to factors like target scintillation, motion, varying clutter and environmental conditions is the potential strength of the proposed radar system. This capability, which is not offered by current SAR systems, introduces a new class of airborne/spaceborne adaptive radars ideal for advanced ATR in urban environments. In this new paradigm, EM signals at any point in space-time will be considered and be exploited to the utmost feasible limits using accurate knowledge of complex radar channels. Hence, interoperability of different radar platforms and sensors is envisioned in this scenario. Notably, the present MIMO SAR concept combines the high-resolution techniques with beamforming, which can significantly enhance the quality of SAR image. The novelty of the present approach to address the core challenges, as opposed to conventional techniques, may be viewed as follows.

The MIMO analytic model of radar channels provides an effective tool and theoretical framework to study and develop the optimal data exploitation algorithm. This tool can be used to design/tailor optimal processing algorithms for target applications and operating conditions, and develop novel adaptive processing schemes for ATR applications. Application of this tool helps to avoid inadequate simplifying EM (propagation & scattering) assumptions used in conventional PolSAR processing techniques. The described model also provides a tool to explore, design and analyze new SAR array configurations. Multi-SAR, hybrid-SAR (SAR and non-SAR radar combination) and hybrid active/passive radar arrangements are among these potential concepts.

The MIMO and multipath formulation of radar as a communications channel opens the way to a new class of space-time processing and optimization techniques that are proven to be highly efficient. Adopting these techniques upon proper modifications in the radar domain introduces new, enhanced and controllable capabilities and functionalities. Adaptive space-time coding of transmit radar signals or pulses is a new concept that makes judicious use of radar channel characteristics to improve quality and optimize the performance under given conditions. This channel coding technique will be used to optimize the operation of radar in different conditions and environments. Hence, the resultant radar will be able to function in complex environments and conditions. It is worth noting that even non-adaptive space-time coding can offer performance enhancement. Space-time coding classification with respect to targets will also provide a mapping opportunity to explore new target classification strategies.

The MIMO approach can effectively handle target radar cross section (RCS) fading and scintillations within the illumination interval. In fact, the proposed MIMO SAR system can capitalize the RCS variations to improve the performance by virtue of the incoherent processing and its multistatic nature.

Introduction of a general radar or PolSAR scheme as a MIMO communication system offers the advantage of overall system optimization using wireless communication metrics such as spectral efficiency and channel capacity. Simulations of SAR based tracking systems [15] and investigations in the field of STAP indicate that considerable spectral efficiency improvement can be achieved by splitting the “long receive antenna” to multiple antennas by the virtue of space diversity. Furthermore, optimal operating modes, such as optimal pulse repetition frequency, can be derived.

This work explores an innovative approach to combine the novel, mathematically efficient and fast-growing space-time techniques to a robust EM model of distributed radar to create advanced designs for surveillance type spaceborne and airborne radar systems. Such advanced and diverse functionality can deliver tailored and precise performance in complex environments and under difficult and non-cooperative conditions.

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List of symbols/abbreviations/acronyms/initialisms

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A new adaptive and distributed SAR (Synthetic Aperture Radar) concept for recognition and imaging of targets with fading, varying and unstable signatures in a complex environment is explored. These targets (e.g., moving targets, targets in presence of strong, variant and potentially intelligent interference) represent an important class of military ATR applications within the complex urban environment that cannot be effectively handled by current SAR systems and techniques. The MIMO (multiple-input multiple-output) approach taken for accurate modeling of the radar system channels provides effective adaptivity for optimal radar mode selection and signal processing and, can handle target radar cross section (RCS) fading and scintillations within the illumination interval. In particular, the proposed MIMO SAR system can exploit the RCS variations to improve the performance by virtue of the incoherent processing and its multistatic nature. The present approach also characterizes a radar system as a wireless communications system to which useful metrics and methods for overall system optimization apply and provides compatibility for integration into a hybrid network.

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SAR, Polarimetry, MIMO, ATR