A SW SIMULATOR PARADIGM FOR SPACEBORNE GMTI PERFORMANCE ANALYSIS IN SEA CLUTTER

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ABSTRACT

Modern system engineering for Spaceborne Radars (SBRs) relies on a rigorous mathematical analysis and related simulation software (SW) tools as an aid to radar performance prediction as well as to support breadboarding activities for novel payloads.
This paper outlines the design paradigm of a SW Simulator for Spaceborne Ground Moving Target Indicator (GMTI) Performace Analysis in Sea Clutter complying to standard policies of system design and development based on Flexibility, Modularity, Interoperability, and Efficiency. Clearly the Efficacy relies on the core engineering issue which has not been faced completely by the scientific and technical community in terms of enabling technologies for SBRs, the thorough applicability of SBR-GMTI techniques to the marine environment in harsh environmental conditions, as well as sea clutter modeling.

1. INTRODUCTION

Modern governmental organizations may exploit Large Integrated Systems as worthy assets within the framework of their Info-Acquisition & Response functionalities. Accordingly in the Acquisition /Detection Phase, a group of sensors senses the environment, acquires data, and provide them to decision-makers via a dedicated telecom infrastructure as an interpreted (i.e. processed) information which has to be actual, accurate and reliable. The decision-makers may then exploit these interpreted information, in order to increase the Situation Awareness before initiating a Response Phase in case a threat/alert is detected. In this case a reaction may commence thus leading to a Rapid Environment Assessment. Clearly the amount of such a rapidity is a crucial aspect depending on the mission profile and is characterized by a specific requirement on the Responsiveness of the Large Integrated System spanning from a vital “early-warning” for the immediate protection of people, national borders and strategic infrastructures to a “quite prompt” reactions in the medium-long term.
Current European Maritime Surveillance operational demands and requirements for promptly monitoring border infringements, traffic safety, environmental hazards, and fishery control are currently aided by microwave Spaceborne Radars (SBR), as well as by passive optical and infrared instruments. In particular, by exploiting consolidated non-real-time synthetic aperture paradigms in terms of raw data acquisition and related image formation processing, Synthetic Aperture Radars (SAR) payloads embarked on Low Earth Orbits (LEO) satellites feed large ground-based data-fusion systems during their Data Acquisition & Response phases.
An indirect maritime surveillance user need is also related to accessing information “as soon as possible” and “as often as possible.” These user needs are inevitably related to the ground and space segment topology, the available telecom infrastructure, whereas the possible "responsiveness" of the SBR product must eventually be interpreted, i.e. scaled by delays several orders-of-magnitudes larger than those required for classical early warning surveillance systems on the ground. In fact ground-based Moving Target Indicator (MTI) heritages (where pop-up targets must be faced with a quick procedural cascade made of "detection-tracking" spanning an amount of time on the order of seconds) are currently not applicable to SBR whereas the neat semantics of surveillance-related terms such as Detection, Tracking, Classification, and Identification must be thoroughly and non ambiguously defined. Within this context this paper will be mainly focused on addressing a SW simulator design-paradigm for Spaceborne Ground MTI (GMTI) performance analysis for maritime surveillance.
Furthermore, ancillary concepts, technological frameworks [1], and related signal processing techniques will also be spanned in order to fit a target-detection statistical assessment within a broader post-detection parameter-estimation framework. It is also worth noting that this paper takes into account results and expertise related to concurring european research programs for maritime surveillance from space such as NEWA, SEABILLA, SIMTISYS, DOLPHIN, the state-of-the-art of Spaceborne GMTI in land and sea clutter as well as modern SW design policies and system engineering methodologies.
The paper structure is organized as per the following sections. Section 2 frames SBR assets for Earth Observation (EO) surveillance. Section 3 defines the role of software (SW) simulation for Spaceborne GMTI performance prediction. Section 4 covers the architectural concept of the aforementioned simulator whereas Section 5 outlines the simulator as a modular system of subsystems. Section 6 highlights the simulator functional architecture, while section 7 addresses the

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subsystems characteristics. Section 8 and 9 provide a geometrical framework for SBR and conclusions respectively.

2. SBR SURVEILLANCE FRAMEWORK

Two types of pulsed SBRs can be taken into consideration: Type II Radars and Type III Radars [2]. Accordingly Type II Radars are Spaceborne SARs providing imaging functionalities, e.g. radars used for non-real-time surface mapping taking into account the backscattering scene as stationary whereas any moving object would appear blurred and/or azimuth displaced [3]. On the contrary Type III Radars are non-imaging Spaceborne Surveillance Radars aimed at providing (not necessarily yet coveatingly Early Warning) MTI functionalities by processing either non-coherent or Doppler-related scattered echoes.

MTI Radars originally appeared as an Early Warning ground based surveillance aid for civil and military applications where a "blip" on a Plan Position Indicator (PPI) display would indicate a closing target [4]. Further evolutions have led to airborne MTI implementations "looking-down" for GMTI aimed at detecting targets within a Cell Under Test (CUT) on the ground. Lastly MTI techniques were extended/investigated on a SAR image obtained onboard an aircraft. Those steps paved the way for investigating spaceborne MTI techniques on Real Aperture Radars (RAR) [5] as well as on SAR images. Accordingly MTI techniques for Type II SBRs are still experimental and so far employ simple multichannel receivers (only 2 antenna phase centers displaced in azimuth are physically employed on a Phased Array Antenna and toggling modes may eventually allow another 1 or 2 additional virtual channels) [6]. Public IEEE literature-hints are also endorsing data-dependent Multiple-Input-Multiple-Output (MIMO) Space-Time Adaptive Processing (STAP) investigations for future MTI applications [7] whereas a universal metric to assess the performance of an MTI technique is still lacking, i.e. different authors focus on different metrics. While the American Space Based Radar plan has been aborted [8], European and Canadian efforts w.r.t. MTI techniques have been focusing on heuristic combinations and augmentations of Displaced Phase Center Antenna (DPCA), Along-Track Interferometry (ATI) and STAP on SAR images. Although DPCA and ATI have been implemented for Type II SBRs, STAP on SAR images has been taken into account from an a-priori Knowledge-Aided (KA) perspective on airborne platforms for traffic monitoring.

Definitely the key factors for future developments of Type II and Type III real-time surveillance SBRs rely on denser constellations, advanced on-board processing and storage capabilities, developments of phased array antennas, as well as telemetry infrastructures [8]. From a surveillance wise-operative perspective it also appears that viable architectural solutions for next generations SBRs might eventually better support, without replacing, airborne surveillance radar operations such as those carried out by the Airborne Warning And Control System (AWACS) and Joint Surveillance Target Attack Radar System (Joint STARS) aircrafts [9]. For the sake of completeness it appears worth clarifying that the Copernicus program, for the establishment of a European capacity for remote sensing EO (comprising C-Band SARs, radiometers, altimeters, as well as multispectral optical satellite payloads), is aimed at providing services based solely on non-real-time Monitoring & Forecasting capabilities.

3. THE ROLE OF SW SIMULATION FOR SBR

SBR systems for SAR mapping jointly with GMTI capabilities rely on an engineering issue at a low Technology Readiness Level (TRL). Such an engineering issue can be theoretically addressed as "Spaceborne GMTI in Land and Sea Clutter." Accordingly Research & Development (R&D) engineering efforts for Spaceborne GMTI should consider "reasonable" steps forward w.r.t. the most "similar" and "operative" radar systems aimed at framing a feasible tailoring, augmentations, and reductions. In particular there are three most similar operative radar systems to be referred to. The first one is related to airborne assets for surveillance. Namely the AWACS in Maritime Mode and the Joint STARS in Wide Area MTI Surveillance Mode. The second one is the experimental SAR/GMTI Modex Mode implemented on RADARSAT2. The third one takes into account the most advanced European SBR systems, e.g. the COSMO-SkyMed satellite constellation.

It is then mandatory underlining a methodological approach which should be based on taking into account public IEEE proceedings, space agencies, defense institutions, as well as current R&D programs of large aerospace & defense contractors. Clearly user-needs should be grasped. Yet an interpreting and re-engineering response by the engineering community to such user-needs is compulsory whereas definitely low TRL engineering issues should not be addressed in compliance to high-level services.

Finally Mathematical Analysis, Computer Stochastic Simulation jointly with breadboarding activities appear as the cornerstone for low-TRL engineering-issues and eventually for simplifying solutions exploiting the processing & storage capabilities of customizable multi-core PC workstations [10], modern programming languages [11] and COTS aerospace development tools [12]. A signal-processing-based stochastic simulation is finally a modern approach and fundamental companion tool for SBR prototyping when modeling approximations for analytical convenience are no longer adequate or when mathematical tractability becomes formidable.

Yet, for the sake of completeness, it is also worth quoting Dr. Simon Watts warnings on results reliability and related exploitation: "*Indeed it may not be obvious how to quantify performance effectively….However, a feature of any useful specification point is that it should be verifiable or measurable*" whereas "*there is a need to quantify the significance of measurements, and a need to understand what is a failed or a successful trial*" [13]. Clearly such a performance uncertainty does not depend on the significant advances and evolutions of radar enabling technologies and digital signal processing techniques but rather on the electromagnetic (EM) complexity of the channel phenomenology in terms of propagation and scattering which directly affects the necessarily adaptive processing of a radar processor. In pragmatic terms radar performance should be "predicted" by advanced modeling via Mathematical Analysis & Monte Carlo Simulation and "validated" by controlled spot trials since any airborne (and eventually spaceborne) test-bench is significantly hard to set up for novel SBR payloads.

4. SIMULATOR ARCHITECTURAL CONCEPT

The Simulator *Architectural Concept* will be defined as a System-of-Subsystems dynamically evolving in time according to a *Discrete-Time-Index-k* as per common System-Engineering methodologies. The modular architecture allows constraining different engineering fields and expertise on specific subsystems as required for the design and development of a modern SW Simulator aimed at investigating Spaceborne GMTI in Sea Clutter. The Subsystems (also known as *Modules*) are shown in the figure reported hereafter

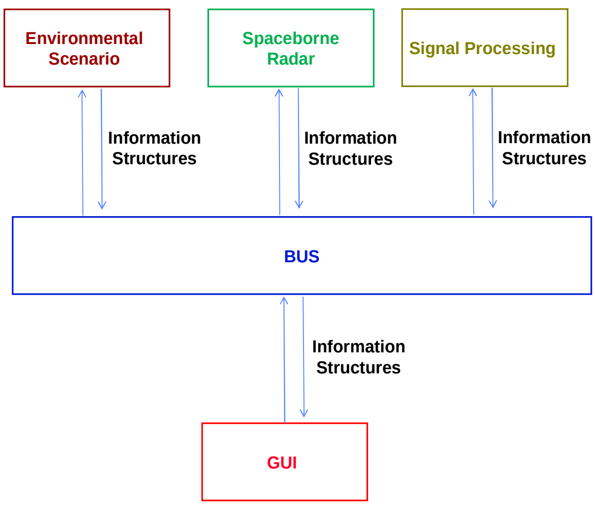

Figure 1. Simulator Model as a Systems-of-Subsystems

Namely an Environmental Scenario Subsystem to be designed by Aerospace Engineers and Geophysicists, a Spaceborne Radar (SBR) Subsystem and a Signal Processing Subsystem to be designed by Radar Engineers, a Graphics User Interface (GUI) Subsystem and a BUS Controller Subsystem to be designed by SW Engineers.

From a *Systematic-Logic* point of view each subsystem should be characterized by state-variables known as Subsystem-Information-Structures which should be available to the other subsystems at each Discrete-Time-Index k through a common Bus. Accordingly the Simulation can be logically considered as a Flow-of-Elaborated-Data whereby each subsystem provides its output Information-Structures to the other synchronized subsystems (i.e. the data are available at each Discrete-Time-Index k).

From a *SW-Architectural* point of view the data elaboration performed by each subsystem can be considered as an independent Workflow. Accordingly each Subsystem-Workflow may start its steps execution (also known as *Task*) serially with the other Subsytems-Workflows and then be synchronized (i.e. time-tagged) at the end of its steps execution. The overall Simulation Workflow Instance (also known as *Activity*) thus results in a group of workflows tagged to the virtual *Discrete-Time-Index-k* which resembles the realistic effect of time-evolution.

Each subsystem Task should be completely executed before providing its synchronized Information-Structures to the other subsystems. The interface between subsystems should be regulated and driven by the BUS Controller, which acts as an active means managing both the communication flows and the involvement of each subsystem in the simulation activities. More specifically the active BUS Controller contains the workflow engine and allows interfacing each subsystem whereas each "processing" subsystem contribution to the simulation Activity is invoked by means of a common message-passing interface mechanism based on a Extensible-Markup-Language (XML) scheme and providing all the necessary Input-Output Information-Structures on standard files. It is worth stressing that there is no need for real-time dynamic interactions between different subsystems executing different tasks belonging to the same on going Simulation Activity. Indeed there is no difference for a subsystem if its necessary input parameters come from a continuous time-tagged stream of data as in a real time scenario or all at once contained in time-tagged data structures to be included in input file/s. Each subsystem task can thus be fed with input parameters configured by the Human Operator and/or provided as the outputs of other subsystems tasks.

5. MODULAR SYSTEM PURPOSE

The subsystems purposes of the aforementioned architectural concept are qualitatively hinted in the subsections reported hereafter.

5.1. Environmental Scenario Purposes

The Environmental Scenario Subsystem is in charge of computing and visualizing both orbiting Spacecrafts and

Earth Entities kinematics belonging to a European Maritime Scenario in a suitable Earth Coordinate Reference System (E-CRS) and Spaceborne Radar Coordinate Reference System (SBR-CRS).
Moreover the Environmental Scenario Subsystem computes an Access to an Area of Interest (AoI) by exploiting “coarse monitoring capabilities” of the radar payload associated to each spacecraft i.e. a simplistic approximation-representation of the Mainlobe Antenna Radiation Pattern (ARP) directed towards an Antenna Pointing Vector (APV) associated to each Radar Payload on board each spacecraft e.g. right/left looking capabilities, minimum/maximum incidence angles .
When the Access-to-AoI Event is flagged an Environmental Scenario geometrical and environmental information (Viewing Environmental Geometry) is computed by exploiting “fine monitoring capabilities” of the radar payload associated to each spacecraft i.e. an Advanced Field of View (FoV) related to the ARP directed towards an APV associated to each Radar Payload on board each spacecraft.
Finally related environmental Quality of Service (QoS) reports are computed thus entangling the SBR-GMTI problem with additional aerospace and/or marine-physics reports which are closely intertwined to the "Spaceborne GMTI in Land and Sea Clutter" core engineering issue.

5.2. SBR Subsystem Purposes

The Spaceborne Radar Subsystem is in charge of representing the received signals for Type II Radars and Type III Radars on board each Spacecraft when the Access-to-AoI Event is flagged since a coherent train of modulated pulses has been transmitted by the SBR. More specifically the Spaceborne Radar Subsystem will exploit the Viewing Environmental Geometry and suitable environmental QoS reports in order to compute received baseband signals to be further processed by signal processing techniques.
The received (Rx) baseband signals for Type II Radars are Digital Complex SAR Images which could be computed within the Spaceborne Radar Subsystem from proper models of SAR digital raw data and further processed by an image formation algorithm.
The received baseband signals for Type III Radars are Digital Complex Envelopes.

5.3. Signal Processing Subsystem Purposes

The Signal Processing Subsystem is in charge of computing signal processing techniques (e.g. MTI, ELINT, Image Processing,…) exploiting the received baseband signals computed by the Spaceborne Radar Subsystem. In particular the MTI signal processing techniques are in charge of investigating the MTI capabilities of Type II Radars and Type III Radars on board each spacecraft constrained to the Access-to-AoI Event.

5.4. BUS Controller Subsystem Purposes

The BUS Subsystem is the common SW-Infrastructure that integrates the subsystems as an active data-transmission channel. It is worth noting that a useful BUS capability allows splitting the logical and complete sequence of Simulation Workflows for a given Simulation Activity into Simulation-Phases (also known as Deterministic Sequential Steps) whereby each Phase implements a subsequence of the complete sequence of workflows. Accordingly archived Simulation Phases (e.g. the sequence of workflow steps associated to an already archived Environmental Scenario or Spaceborne Radar) can be pre-selected thus allowing the repetition of a Simulation Activity when the focus is on a specific workflow solely (e.g. the Signal Processing workflow). The BUS workflow engine should be able to manage all these types of workflows, driving the executions of the steps in the right order and/or concurrency.

5.5. GUI Subsystem Purposes

The GUI Subsystem is in charge of monitoring and controlling the simulation. A useful feature of the GUI should allow representing significant data from the Environmental Scenario with a 2D/3D Graphics Engine (e.g. STK AGI Viewer) e.g. vessels positions and spacecrafts projections on the Earth surface as Tracks to be visualized with a 2D Graphics Engine or spacecrafts orbital trajectories to be visualized with a 3D Graphic Engine in a suitable E-CRS. The GUI can be based on several tabs, each one related to the console main features. Namely

- A Workflow browser, for the monitoring & control of the running/executed tasks.
- A Catalogue browser, allowing to search the catalogued and archived results of previously executed simulations.
- A Request Generator, allowing the operator to ask for a new simulation activity, choosing among the available request templates. In this context, it should be possible/mandatory to insert the input parameters necessary to generate a new instance of the simulation; it should also be possible to directly access the catalogue to search and select archived intermediate results as input for the next steps of the simulation activities.
- A Report, allowing to generate and visualize Performance Analysis Reports (e.g. tables, plots,...) based on results of the performed tasks.

Within each tab, graphic controls such as buttons, clickable icons etc. should be available to open contextual windows, to visualize further details or access specific features of each performed task.

6. FUNCTIONAL ARCHITECTURE

The Simulator Functional Architecture is represented in Figure 2:

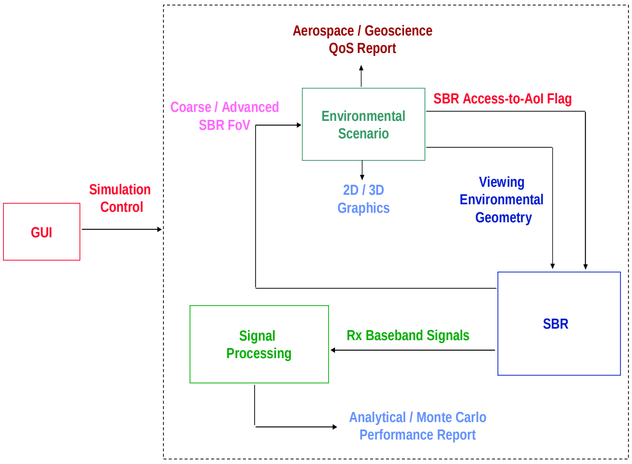

Figure 2. Simulator Functional Architecture

As all subsystems Information Structures and boundary conditions (e.g. simulation start-time(s), simulation end-time(s), simulation time-step(s),…) have been initialized the simulation can begin and the simulation flows in time according to a *Discrete-Time-Index-k*.

Accordingly the Environmental Scenario Subsystem evolves in time. All spacecrafts and targets positions at each discrete-time index are computed by a propagator and a configured kinematics respectively whereas a 2D/3D graphic engine allows displaying the overall scenery dynamics and Aerospace & Geoscience Reports are computed.

At each discrete-time index, and for each orbiting spacecraft, the Earth surface pointed by a Coarse FoV (related to the SBR ARP and APV) is compared to an Earth AoI as a geometric set-intersection test. As soon as a suitable intersection test exists (i.e. an Access-to-AoI Event is present), a SBR Access-to-AoI Flag is switched on. When the SBR Access-to-AoI Flag is switched on, the SBR functions are activated solely during a temporal interval known as a Radar Acquisition Time (RAT) to be configured i.e. positioned within the Access-of-AoI Event (e.g. at the beginning or in the middle of such an event).

The Radar Acquisition Time is the most general concept related to the temporal interval associated to a CUT assessment within the AoI which may comprise SBR transceiver operations intervals, SBR coherent / non-coherent signal processing times, as well as SBR multilook echo acquisition intervals. More specifically the RAT may take into account signal transmission and propagation temporal delays and, depending on the context, can be tailored to embody different common-literature temporal meanings in the radar receiver such as Coherent Processing Interval (CPI), Non Coherent Interval (NCI), Dwell Interval (DI), Dwell Time, Processing Interval, Temporal Window, or a combination of them.

The type of propagation and scattering modeling assumptions of the channel phenomenology as well as the advanced SBR FoV during a RAT allows the SBR Subsystem to exploit the Viewing Environmental Geometry computed by the Environmental Scenario in order to feed suitable baseband signals to the Signal Processing Subsystem (i.e. expressed by deterministic and stochastic parameters related to the propagation and scattering modeling assumptions of the channel phenomenology).

The signals stored i.e. associated to the RAT are fed to the Signal Processing Techniques for MTI which will provide a binary hypothesis assessment of whether or not an unknown-in-dynamics non-cooperative moving target is present within the CUT. In general terms the target detection assessment can be performed by 2 cascaded operations:

-Forming a likelihood ratio from the signals stored during the Radar Acquisition Time.

-Comparing such a likelihood ratio with a Threshold.

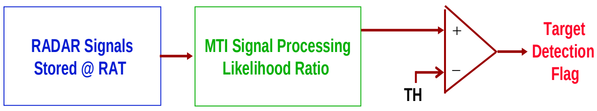

Figure 3. MTI Signal Processing Likelihood Ratio

Once a target is detected, an ancillary processing may also be employed to estimate the target signal parameters and refine the initial detection information by parameter estimation.

Given the stochastic nature of some of the parameters of the signals, Monte Carlo simulation techniques can be carried out where the MTI Threshold Comparison is repeated a number of times chosen as a function of the accuracy on the estimation of the detection and false alarm probabilities. At each trial the stochastic parameters can be initialized according to their modeled Probability Density Function (PDF). An estimate of the Probability of Detection P_d within its specified tolerance limit [14] can be written as

$$\hat{P}_d = \frac{1}{N}\sum_{i=1}^{N} F_i \tag{1}$$

where F_i is the [1/0] Flag for the *i*-th [detection /no-detection] assessment respectively. The above mentioned procedure can be carried out according to different Boundary Conditions (BC) e.g. for a range of operative Signal-to-Interference Ratios (SIRs), Sea States, Target Dynamics, Target Radar Cross Sections (RCSs) as shown in the Logic Flow Block Diagram below

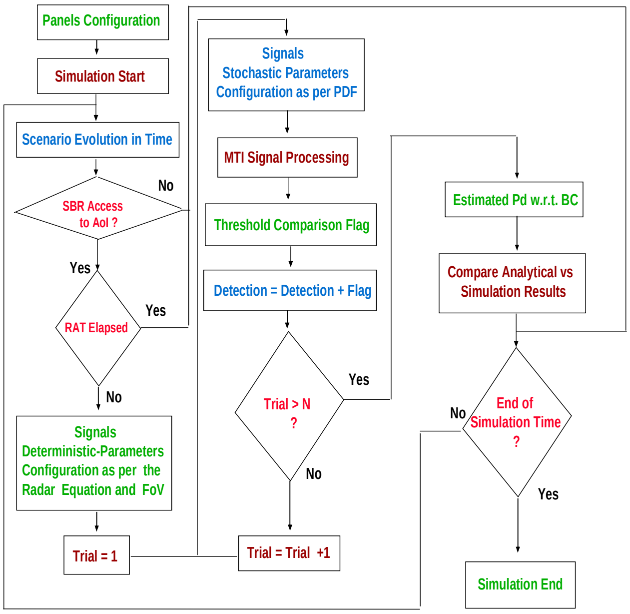

Figure 4. Logic Flow for a Simulation Activity

The Simulator is finally aimed at computing Signal Processing performance reports in order to compare (whenever possible) analytical findings with simulation results obtained with Monte Carlo techniques. It is worth noting that a wise design and development of the simulator allows extending the simulator key modeling assumptions (i.e. the simulator efficacy and scientific content) by focusing solely on key information-structures. Namely an *Advanced SBR FoV, a Viewing Environmental Geometry, RX Baseband Signal(s).*
Therefore different researchers could assume different models to be constrained within expansions and/or improvements of the above mentioned key information structures whereas the Simulator Functional architecture and SW Infrastructure remain the same.
Clearly the requirements on the *RX Baseband Signal(s)* should drive the requirements on the *Advanced SBR FoV* first and eventually the requirements on the *Viewing Environmental Geometry.* The requirements on the *RX Baseband Signal(s)* should also drive further requirements on the environmental (i.e. Aerospace & Geoscience) QoS Reports in order to take into account SBRs within a KA Design paradigm.
The *Workflow Engine* implements an Operational Flow, according to checkboxes & parameters configured by the Human Operator on the GUI before running the associated Simulation Activity. More specifically the Workflow Engine implements such an Operational Flow according to the following Deterministic Sequential Steps outlined in the following table.

Table 1: Simulation Sequential Steps

Step Number	**Task Execution**
#0	*GUI Configuration*
#1	*Environmental Scenario for Aerospace QoS*
#2	*Environmental Scenario for Geoscience QoS*
#3	*SBR Pre-Operational Advanced SBR FoV*
#4	*Environmental Scenario for SBR Signal Processing*
#5	*SBR(s)*
#6	*Signal Processing*
#7	*Simulation Results*

7. SUBSYSTEM CHARACTERISTICS

The Simulator SW Architecture should allow transferring the necessary Information Structures (stored in suitable *Data Structures* within a HDF5-compatible file or provided by the human operator, through the GUI, directly as a XML file) via the Bus infrastructure.
Accordingly after reception of a request from the Human Operator through the GUI, the Subsystems Input/Output Files are ready to be managed by the Bus in order to run a Simulation Activity according to the deterministic sequential steps hinted in Table 1.
In summary the Information-Structures handled by each subsystem should be organized in well defined *Data-Structures* (also known as *Subsystem Ephemerides*) within suitable *Subsystem-Data-Files* (e.g. HDF5 file or a similar one) and exchanged through the BUS via a XML-based protocol.
The description of the Subsystems Interfaces in terms of the INPUT DATA STRUCTURES and OUTPUT DATA STRUCTURES can be sketched as per the following Object Oriented Paradigm shown in Figure 5 where each subsystem is represented as a Black-Box.

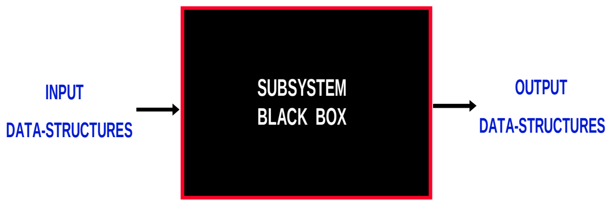

Figure 5: Subsystem Black Box Concept

The INPUT / OUTPUT DATA STRUCTURES of each subsystem should be outlined within a table (as shown in Table 2 and Table 3) whose columns entries are:

- Input Information Structure (indicating the “Parameter” from a qualitative-semantic point of view, i.e. a neat linguistic description of the Parameter to be employed).
- Input Data Structure (indicating the “Parameter” from a quantitative-syntactic point of view, i.e. the SW metadata that contains the Parameter such as the name, type,…).
- Clarifying Description on Input (indicating a significant additional comment, if any, which could not be conveyed within the Input Information Structure entry).
- Output Information Structure (indicating the “Parameter” from a qualitative-semantic point of view, i.e. a neat linguistic description of the Parameter to be employed).
- Output Data Structure (indicating the “Parameter” from a quantitative-syntactic point of view, i.e. the SW metadata that contains the Parameter such as the name, type,…).
- Clarifying Description on Output (indicating a significant additional comment, if any, which could not be conveyed within the Output Information Structure entry).

Table 2: INPUT DATA STRUCTURES

Input Information Structure	*Input Data Structure*	*Clarifying Description*
…	…	…
…	…	…

Table 3: OUTPUT DATA STRUCTURES

Output Information Structure	*Output Data Structure*	*Clarifying Description*
…	…	…
…	…	…

The description of the Subsystems Quantitative Models embody the scientific content of a line-of-research. Accordingly the Quantitative Model should be outlined in terms of:

- neat descriptions;
- executive summary;
- internal block schemes and related signal processing flow;
- analytical formulas and related derivations;
- references to proofs of statements;
- major modeling assumptions and approximations;
- SW code in case of any numerical computation result;
- tables and figures;
- conclusions and way forward.

8. GEOMETRICAL FRAMEWORK

Type II and Type III SBRs for Maritime Surveillance orbit around the Earth according to Newtonian Mechanics whereby the Earth exerts the central force. More specifically, after the Launch & Early Orbit Phase (LEOP), a SBR moves around the Earth on an elliptical orbit with a small eccentricity while the Earth keeps rotating around its own axis. The gravitational effects of the Sun, the Solar System planets, and the Milky Way bodies, which exert their central force on the Earth, as well as the Earth atmospheric drag, the solar and albedo radiation pressure on the spacecraft, the spacecraft thrusters, the Earth oblateness, the Earth non-homogeneous and non-stationary mass density, and eventually relativistic effects are neglected on this SW simulator paradigm. Such an approximation is indeed reasonable during a Type II and Type III SBR RAT elapsed time and related QoS results.
The altitudes of SBRs for Maritime Surveillance fit LEOs within the innermost Van Allen radiation belt. Such altitudes protect the Spacecraft from debris and particles flows, limit to a certain extent the atmospheric drag, and guarantee an adequate radiometric performance for Type II imaging radars with current space-qualified technologies. Indeed, considering current space qualified transceivers as well as antennas constraints and trade offs, Geostationary, Medium Earth Orbits (MEO), and Molnya orbits are not tailored to a sufficient radiometric performance for an efficient SAR Image Formation.
While airborne SAR or GMTI radars may model the Earth as a flat, non-rotating surface, Type II and Type III SBRs must model the Earth as a curved and non-stationary i.e. rotating surface with a significant impact on the performance of MTI techniques for Maritime Surveillance.
Different inertial reference frames are useful for Maritime Surveillance SBRs whereas a general 3D Inertial Reference Frame for Maritime Surveillance SBRs can be described for simplicity within the framework of a Cartesian Coordinate System by:

- An origin *O*.
- A *Fundamental Plane* characterized by its Normal.
- A *Principal Direction* on the Fundamental Plane.
- A *3rd Axis* generated using for example the Right Hand Rule.

Finally, considering radar engineering and related modeling (in particular for SBRs for Maritime Surveillance), an Inertial System exists and can be pragmatically assumed by referring to *"distant"* stars e.g. the First Point of Aries, the First Point of Libra,…

9. CONCLUSIONS

A SBR-GMTI Simulator Architectural Requirements can be described according to the following main points based on the methodology for "Instrument Performance Specification & Measurement" described by Dr. Simon Watts [13]:

- Instrument
- User Needs
- Specifications on Performance
- Measuring Performance
- Modeling Scenario

The aforementioned Simulator is a Software (SW) Tool whose functionality is a Simulation of Maritime Surveillance Performance from SBRs on a PC Workstation adopting Leonov's "Simulation" definition on [15] as "*running computer-based algorithms that reconstruct mathematical equations and operators describing a system or its performance.*"

The Core Engineering Issue is related to the Radar Problem: "Spaceborne GMTI in Sea Clutter."

Two types of SBRs can be taken into consideration: Type II Radars and Type III Radars [2]. Spacecraft constellations and orbital mechanics could be constrained to those LEO orbits suitable for Type II Radars operations e.g. Terrasar X (~ 500 Km height), Cosmo Skymed (~ 620 Km height), Radarsat 2 (~ 800 Km height). Surveillance Areas could be tailored to those European hot spots requiring a maritime watch dog (e.g. vessels in the Mediterranean Sea, the English Channel,…).

The SW infrastructure should comply to standard policies of system design & development, i.e. Flexibility, Modularity, Interoperability, and Efficiency whereas the Efficacy relies on the core engineering. Accordingly the modeling assumptions account for the scientific validity taking into account Dr. Simon Watts wisdom [13]"*...the effects of sea clutter can have a very significant impact on detection performance. If these effects are not modelled realistically in the design process, it is unlikely that a radar system will fully meet its operational requirements.*"

Specification on Performance should be based on Moving Target Indicator (MTI) requirements w.r.t. an Optimization Criterion, e.g. the Neyman Pearson Criterion whereas the Measuring Performance could be based on comparing Analytical Results with Monte Carlo Simulation Results (wherever possible) based on MTI requirements w.r.t. Decision Theory, e.g. Binary Hypothesis Testing.

Due to the complexity of analytic models for the electromagnetic EM scattering from hydrodynamic surfaces and from complex targets, the Modeling Scenario can be characterized via a signal processing approach with both deterministic and stochastic parameters.

The SW Simulator Paradigm comprises different subsystems to be flexibly updated in an ever increasing level of detail whereas the SW infrastructure design efforts indeed should be aimed at developing a non-real-time XML-based message passing scheme among different modules spanning aerospace and electrical engineering fields as well as geophysics. Namely spacecrafts orbital mechanics comprising mission analysis, environmental scenarios comprising both littoral and sea clutter patches, static and dynamic targets, atmospheric boundary conditions, modern radar signals encompassing both coherent and non-coherent pulse trains at relevant operative frequency bands, onboard raw data acquisition and related MTI techniques spanning both Real and Synthetic Aperture paradigms as well as Single Input Single Output (SISO) and Multiple Input Multiple Output (MIMO) diversities.

Within this framework the aforementioned Simulator Paradigm allows assuming different models to be constrained within expansions and/or improvements of the key subsystems data structures whereas the Simulator Functional Architecture and SW Infrastructure remain the same. Accordingly this paper paves the way for a Standardized SW Simulation Design Methodology for European researchers in SBRs exploiting modern distributed arrays programming on multicore-processors workstations.

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