A Combined Spaceborne Synthetic Aperture Radar (SAR) Simulation Tool for Both System Engineering and Operational Purposes

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Abstract Satellite simulators for Synthetic Aperture Radar (SAR) can be categorized into two main classes according to its functional use: System Engineering Simulator or Mission Simulator. A system engineering simulator provides a high fidelity infrastructure for SAR system designers to determine or adjust the parameters of the system to realize the requirements. A Mission Simulator behaves as the whole system for mission planning or training purposes.

In this paper we will present a simulator which aims to combine these two main types of simulators in a functionally feasible way. The main purpose is to combine the already designed tools and achieved know-how from the two domains into a single product which can be used throughout the whole project. The system engineering simulator will provide the data required during the design phase and also it will provide a baseline to extend the Mission Simulator Capabilities for detailed mission analysis or training. At the same time the Mission Simulator will improve the engineering simulator in the early phases of the project to give an insight about the mission to the designers of the payload.

The combined simulator enables the operator to imitate an operational scenario with platform statistics and with an expected SAR image product. Moreover, the mission simulator together with the engineering simulator support can be used to train the operators to select the best opportunity out of several options for the best output.

Turkish company STM has been working on the development of the simulation infrastructure defined above. STM's main competencies are engineering, technology and consultancy.

Keywords-SAR; simulation; satellite; ground segment; space segment; raw data; mission planning; training

I. INTRODUCTION

Synthetic Aperture Radar (SAR) systems are important and popular remote sensing systems. SAR systems are used at both airborne and satellite platforms. When SAR sensors are compared with optical sensors, main advantages of SAR sensors are:

- Imaging capability at both day and night
- Operating capability independent from weather conditions
- Generation of information about both human made targets and the structure and parameters of the observed earth surface (elevation, material type, and etc.)

SAR sensors have both military and civilian applications. Basic military applications of SAR sensors are reconnaissance, intelligence and recognition. Some of the civilian applications can also be listed as below:

- Agricultural and Forest Monitoring
- Environmental Monitoring (snow, ice, pollution)
- Surface Topography and Mapping
- Ship Traffic Monitoring
- Monitoring of Disaster Damages
- Hazard Identification

SAR is a remote sensing system which uses radar principles in order to generate images by using the backscattered signals from the observed scene. SAR uses the doppler history of the radar echoes generated by the forward motion of the platform (airborne or satellite) in order to synthesize the effect of a large antenna which is not feasible to mount to the real platform. By this concept of synthetic aperture, high azimuthal resolution can be obtained despite a physically small antenna.

Modeling and simulation tools are widely used for remote sensing purposes. There are many SAR simulation tools which are developed for either commercial or academic purposes and these simulation tools try to meet some of the needs below:

- Determination/selection of SAR system parameters at payload design phase
- Mission planning for SAR payload
- Training of SAR payload operators

Modeling and simulation tools provide a systematic and low cost way of satisfying these kinds of needs.

II. DISCUSSION OF CURRENT SIMULATION APPROACHES

In this article, two main SAR simulation approaches which are completely different will be discussed. These approaches may be mentioned as "System Engineering SAR Simulator" and "SAR Simulator for Operational Purposes". Before deciding on which type of SAR simulator is needed, the basic requirements and the purpose of procurement of such a simulation tool shall be clarified.

A. System Engineering SAR Simulator

System Engineering SAR simulators are developed for the engineering needs of the SAR sensor design team during the project development lifecycle. These engineering needs include specification of sensor requirements, determination of design parameters and validation/verification of the sensor. In order to specify the applicable requirements correctly, the purposes, the possible achievements and the limitations shall be analyzed. SAR simulation is an efficient way for this analysis and feasibility study. Also during the design phase of the SAR sensor many analyses and iterations are needed in order to determine the optimum set of parameters which satisfy the requirements of SAR payload. SAR simulators provide an agile and flexible environment in order to select the optimum set of parameters for the SAR payload which is under development. These design parameters contain both hardware and software parameters. Antenna type and dimensions, transmitter parameters (like PRF, pulsewidth and transmitted power), receiver parameters (like gain, noise characteristics and sampling rate) can be given as examples for hardware parameters. Also the signal processing algorithms are modeled at such SAR simulators. The possible signal processing and image formation algorithms (like Range-Doppler Algorithm, Polar Format Algorithm and Chirp Scaling Algorithm) and parameters of these algorithms (like weighting window coefficients, and autofocusing) can be selected from processing alternatives of SAR engineering simulators. SAR engineering simulators also model the flight dynamics of the platform (either airborne or satellite) which carries the SAR payload. By this capability, the engineering team has the chance for observing the effects caused by the deviations from the ideal flight path during mission. Therefore the engineering team can analyze these effects before the actual flight tests and they can develop methods in order to eliminate these kinds of unintentional deviations. After the design and implementation/production phases, SAR simulator is still a skillful and valuable tool for the engineering team for validation and verification purposes. It can generate the input raw data in order to feed to actual sensor and the resultant processed images in order to compare with results of the SAR sensor.

According to the required capabilities of system engineering SAR simulators mentioned at paragraph above, these tools shall have high level of fidelity and be based on actual mathematical models instead of some approximations. System Engineering SAR simulators shall have a very detailed set of input parameters depending on the complexity of simulation needs. System Engineering SAR simulators shall generate first the raw SAR data and then the SAR image by processing this raw data with the selected set of parameters. Most of the time the most time consuming part of these simulations is the generation of raw data in a high fidelity way for a high resolution scenario. Therefore most of time, System Engineering SAR simulators shall not have real-time or near real-time operational requirements. It takes a long time to get the result depending on the complexity of the simulation and the fidelity of the tool.

B. SAR Simulator for Operational Purposes

SAR simulators for Operational Purposes are developed for the customer, especially the operators of the actual SAR sensor. This type of SAR simulator is needed during the active utilization period of the SAR system. It can be used for not only the effective mission planning but also the training of operators also. Therefore such a simulator is a valuable and low cost way for defining the optimum mission parameters for satisfying the needs of the user and training the operators. These operators are both sensor operators and exploitation operators. As a training tool, operators can practice on controlling the payload and foreseen the possible effects of the platform, environment and the selected scenario parameters on the resultant SAR images. Also operators can play with these tools by changing the scene and payload parameters and observe the results very fast.

According to the required capabilities of SAR simulators for Operational Purposes mentioned at paragraph above, these tools may have a lower level of fidelity as compared to System Engineering SAR simulators and may use some approximations in order to produce the result very fast. SAR simulators for Operational Purposes shall have a limited set of input parameters which can also be modified for the actual sensor for the mission. Also SAR simulators for Operational Purposes may generate directly the resultant SAR image without generating the raw SAR data. Therefore this type of SAR simulators can operate very fast. Most of the time, SAR simulators for Operational Purposes have real-time or near real-time operational requirements.

III. PROPOSED ARCHITECTURE

A. STM Infrastructure for System Engineering Simulator

STM Savunma Teknolojileri Muhendislik ve Ticaret A.S. (STM) has been working on radar and simulation programs. STM has already been developing a SAR simulator which is named as “SARGUS”. SARGUS is the abbreviation of “Simulation System for SAR Earth Observation Satellite” in Turkish. SARGUS is a skillful tool which provides the engineering team an end-to-end SAR simulation capability. SARGUS is developed to fulfill the system engineering demands mentioned at the previous section. SARGUS models the environment, the moving and stationary targets on the scene, the satellite platform which carries the sensor and the sensor (hardware and software parameters). It is a scenario based tool which allows the user to define different scenarios with various scene, target, platform and sensor combinations.

SARGUS is capable of simulating raw radar data obtained in different orbit, environment and target scenarios. The simulated raw data or the external raw data obtained from real SAR platforms (for ex. ERS-1/2, RADARSAT etc.) can be processed with different well-known signal processing algorithms. Additional algorithms can be integrated to SARGUS easily because of its modular architecture.

Basic architecture of SARGUS can be seen at Fig. 1.

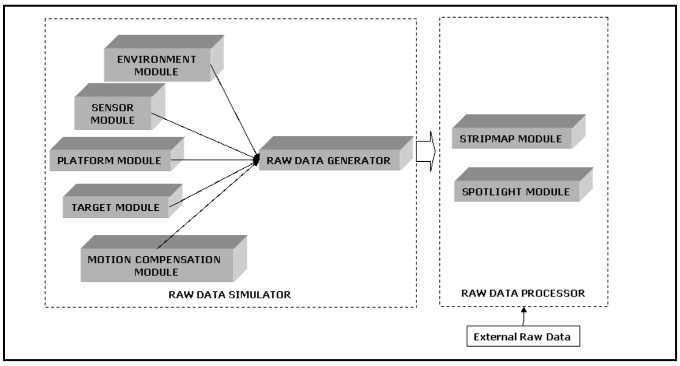

Fig. 1. SARGUS Simulator modules

Environment modeling capability of SARGUS allows the user to define a scene with a digital elevation map (DEM) and different surface types with different backscattering coefficients. It is possible either to use real DEMs or generate synthetic DEMs with SARGUS. Also moving or stationary targets which are modeled in 3D by point-scatterer approach can be located on this scene. The platform module models the orbital characteristics and dynamics of the satellite. Fig. 2 displays a sample screenshot for environment modeling capabilities of SARGUS.

SARGUS has also allows the operator to define the hardware characteristics of a well-known sensor or an experimental sensor and model this sensor in order to generate raw SAR data belonging to this sensor. SARGUS can model sensor hardware parameters such as antenna dimensions and antenna pattern, transmitter and receiver characteristics and measurement devices.

The operator can select different algorithms with different parameter combinations in order to process raw data either generated by SARGUS or belonging to a real SAR payload and obtain resultant SAR images. Then the operator can analyze the performance of algorithms and selected parameters.

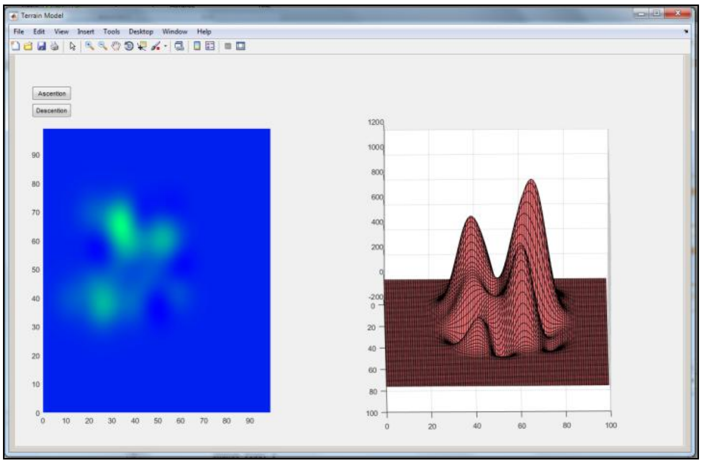

Fig. 2. Environmental Modeling GUI

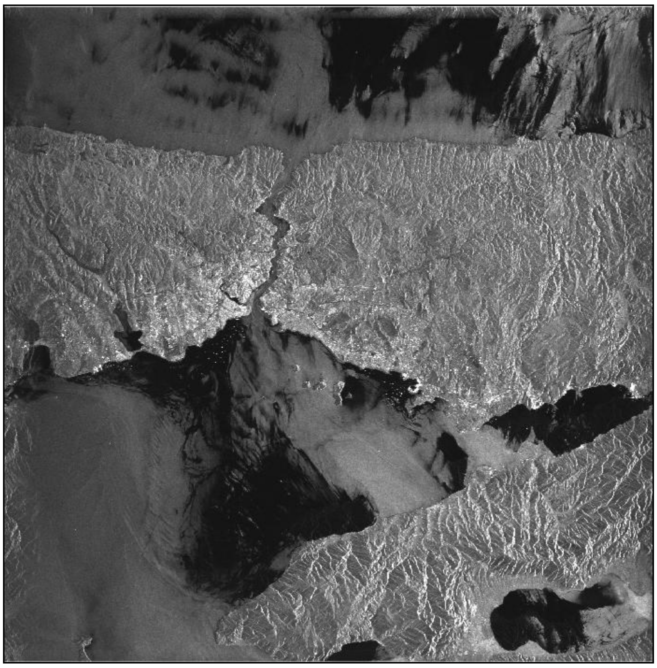

Fig. 3. SAR Image Generated from ERS-1 Raw SAR Data by SARGUS (Istanbul, Turkey)


Fig. 4. SAR Image Generated from RADARSAT-1 Raw SAR Data by SARGUS (Vancouver, Canada)

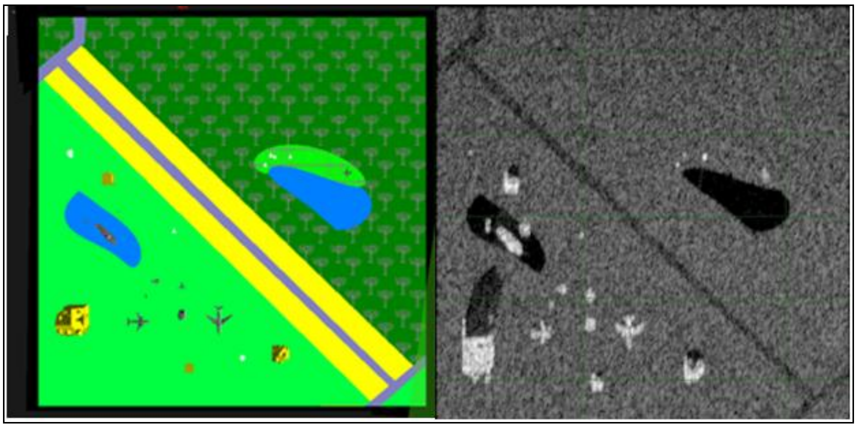

Fig. 5. SARGUS Output Image of a Complex Simulated Scene with 3D Models

B. Mission Simulator Architecture

The main goal of the Mission Simulator is to simulate a satellite mission with its all elements and model the interaction between these elements. These elements are the space segment and the ground segment.

1) Space Segment Simulation

The simulation of the space segment has been studied and implemented in the scope of several different projects. The fidelity and the complexity of the simulations vary depending on the requirements and the use cases. However, there are several generic models (or design philosophies) shared between these simulators. These can be listed as follows:

- Spacecraft Orbit Dynamics Simulator
- Spacecraft Attitude Dynamics Simulator
- Environment Simulator
- Power Generation and Dissipation Simulator
- Thermal Behavior Simulator

The architecture of the Space Segment Simulator is given in Fig. 6.

The attitude of the spacecraft, i.e. the orientation of the body coordinate system with respect to the orbit coordinate system, is one of the key data required by the mission simulator. For example, the attitude information is required to calculate the power generation of the solar arrays, since the power generated by the solar cells is directly proportional to the incidence angle of the Sun light on the cells. In addition, the calculation of the area covered on Earth by the SAR beam is only possible if the attitude information is available. The attitude dynamics simulator predicts the attitude of the spacecraft for a given time in the orbit. This simulator may include the simulation of several actuators (e.g. reaction wheels, magnetorquers, etc.) and may predict the outputs of the on-board sensors (e.g. Sun sensors, magnetometers, Star trackers, gyroscopes, etc.) if required by the rest of the system. For the proposed system, the sensor output is not required, since the on-board software is not in the scope of verification using this simulator. The modeling of the actuator may also be replaced with a predefined attitude behavior for the sake of system simplicity. This lets the system to be relatively simple and still provide attitude data to the rest of the system.

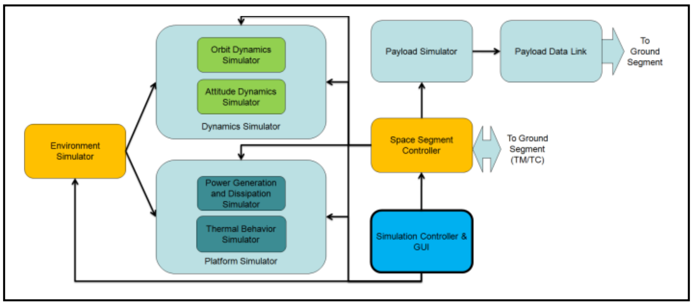

Fig. 6. Architecture of Space Segment Simulator

The goal of the Environment simulator is to calculate the positions of the celestial bodies (e.g. the Sun, the Moon, other planets, etc.) to be used by the rest of the system. Although the data generated by this unit is important for some units in the system (e.g. the orbit dynamics simulator for the calculation of the disturbances), the environment simulator may be simplified significantly with a minor degradation in the fidelity. In fact, the calculation of the position of the Sun [2] is sufficient for most of the required data by the rest of the space segment simulator.

The power generation and the thermal behavior simulators calculate the generated power by the solar arrays and the thermal behavior of the space segment, respectively. These simulators are usually modeled as plug-ins to the space segment simulator so that they can be unplugged from the system in case the data generated are not required. Especially, the date generated by the thermal behavior simulator is rarely used and this simulator is usually omitted. In addition these simulators may be replaced by the predefined power and thermal profiles for system simplicity.

2) Ground Segment Simulation

The ground segment of the mission simulator is the controlling unit of the mission simulator. The level of detail simulated by this simulator depends on the use cases of the mission simulator. If a very detailed and realistic training is planned using this simulator, every single unit in the ground station must be simulated with possible failure scenarios. This is not possible in the early phases of the project, when the specifications of the ground station and the rest of the system are not well defined. The development of such a simulator must be carried out in parallel with the real system throughout the project.

On the other hand, for the purposes of early mission analysis and feasibility, only major elements of a possible ground station can be implemented. For example the whole communication path need not be simulated in detail. It can be replaced with only a delay element between the space segment and the ground station. This limits the capabilities of the simulator but it does not affect the basic mission planning and space segment controlling. In addition it significantly reduces the system complexity and development time. The proposed system architecture can be seen in the Fig. 7.

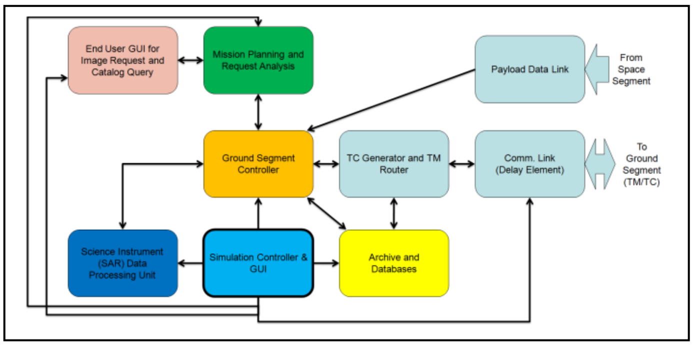

Fig. 7. Architecture of Ground Segment Simulator

The simulation operator controls the system via the Simulation Controller & GUI. All the other units in the ground segment simulator can be controlled by this GUI. This allows the simulation operator to have a total control on the system even though the individual units can operate automatically.

The end user, i.e. the entity that is the final user of the SAR data, is simulated via the End User GUI. The imaging requests and catalog queries are entered from this GUI. Then the Mission Planning and Request Analysis unit analyzes this request or query to fetch it from the database or plan a new SAR survey for the given target area with the required scenario. Then this scenario is provided to the Ground Segment controller unit which is converted to telecommand lists and these lists are sent to the space segment via the TC Generator and then the Communication Link. They are also stored in the Archive. When the mission is accomplished on the space segment side and the science data, i.e. the SAR raw data, is downloaded via the Payload Data Link unit and first stored in the archive. Then it is sent to the SAR data processing unit and the obtained SAR image is send to the archive unit for cataloguing. The data processing in this unit is merely for appearance. There is no actual SAR image generation in this unit. It only outputs a preloaded SAR image which represents the required SAR image. Then the image is sent back to the End User by the Mission Planning unit.

All this data flow is monitored by the Ground Segment Controller and then reported to the Simulation Controller & GUI for visualization.

The interface between the Space Segment and Ground Segment simulators are via the TM/TC and Data Communication Links and the through the Simulation Controller & GUI. The communication links are the simulation of the real data path from the space segment to the ground segment. On the other hand the data path passing through Simulation Controller & GUI is simulation purposes only. For example, the environment simulator is present only in the space segment and its output is used on both space and ground segments.

The Mission simulator given above is sufficient to simulate a mission starting from a request from the user, then performing the SAR survey on the space segment, downloading the data generated on the SAR payload (representative fake data), processing this data on-ground and providing the user with the final result. In addition the data generated by the space segment (e.g. the spacecraft position data, generated power, etc.) can be analyzed for mission performance.

C. Integration of Two Simulators

The main goal of the combined simulator for a Satellite SAR System proposed in this paper is to integrate the two simulators mentioned above for a better understanding of the overall system. As mentioned above the engineering simulator, namely SARGUS, is a very powerful and capable tool for SAR raw data generation and processing. However, it is not aimed for a whole mission simulation. A vast amount of initial data input is required for raw data generation and the targets and surface topography must be modeled prior to simulation. The data generation time is not suitable for online (or real time) simulation. On the other hand, the mission simulator includes a SAR data generator and processing unit for only demonstration purposes. They are functionally representative units and they generate only fake or preloaded data. It uses power dissipation profiles for the SAR payload and these profiles are usually average constant values provided by the payload manufacturer.

The combination of these two simulators aims to combine the raw data generation and detailed payload simulation capabilities of the SARGUS with the environmental and system simulation capabilities of the Mission Simulator. In order to connect the two separate simulator together by using the already available components, a special interface is prepared. The SARGUS requires the position and the attitude of the platform to calculate the reflectance from the Earth surface. This data is provided from the Mission Simulator (i.e. the space segment orbit and attitude dynamics simulators). In addition, the target area geography on the Earth must be modeled. This is automatically performed using the already available DEM importing property of the SARGUS. The scenario editor from the SARGUS is also used to enter example targets in the surveyed region. On the other hand, the SARGUS can estimate the power consumption of the SAR payload at any given time depending on the generated pulse. This data is supplied to the Mission Simulator for Power Generation & Dissipation Analysis. This will provide a better understanding of the power requirements of the spacecraft platform for the possible SAR survey scenarios.

In addition, for the training purposes, the SARGUS can be equipped with additional payload TM generation unit. This unit provides basic housekeeping telemetry (temperature values, current values, basic DSP parameters, etc.) that is generated on the payload only. The failure scenarios can also simulated on these TM values in order to validate the failure counter measures.

The interface that connects the two simulators can be seen in the Fig. 8.

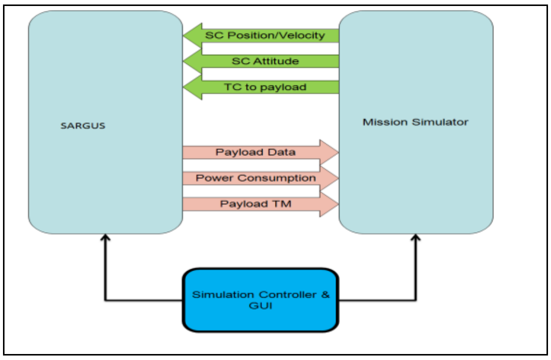

Fig. 8. The Interface between the connected simulators

IV. EVALUATION OF SARGUS AND FUTURE ENHANCEMENTS

STM has been developing SARGUS for the simulation needs of spaceborne SAR programs in Turkey. It's mostly focused on the SAR payload. Although SARGUS has advanced capabilities as a system engineering simulator, it has limited capabilities for operational purposes. The existing modules of SARGUS are displayed at Fig. 1.

In order to achieve the combined SAR simulator infrastructure with the currently available know-how and products in STM, SARGUS is going to be modified to be used as the system engineering simulator. Presently, the spaceborne SAR payload simulation capabilities of the SARGUS are limited. It requires additional mathematical models in order to estimate the effects of the atmosphere. On the mission simulator side, the main modules of both space segment and ground segment shall be developed depending on a generic model. These modules shall be configurable in order to simulate different SAR satellites and missions.

The first version of the Mission simulator will only simulate the orbit dynamics of the space segment so that the position and the velocity of the spacecraft can be fed to the engineering simulator in real time and the corresponding outputs from the SAR payload can be extracted. This requires the implementation of the orbit dynamics simulator and environment simulator blocks shown on Fig. 6. On the other hand, the SARGUS is being improved for better spaceborne SAR platform simulation, as mentioned above. It is also enhanced with additional units that are going to simulate the payload TM generation.

The current SARGUS implementation is still far away from providing real time raw SAR data to the mission simulator. It either gets the inputs as a batch and creates the raw data offline based on these data, or simply generates the raw data for each set of position and velocity pair in a long time. The first resolution to this timing issue is to predict the final SAR image for the given input without generating the raw SAR data. This reduces the required processing significantly, but a lot of capabilities gained by generating the raw data are lost. The simulation operator will be in charge of the type of the operation of the SARGUS depending on the use case of the combined simulator.

The next version of the simulator is planned to include all the units listed in Fig. 6 and Fig. 7. Moreover, additional analysis modules will be added which will analyze and visualize the data generated on both sides of the simulator.

V. CONCLUSION

In this paper two current approaches depending on system engineering and operational purposes for simulation of spaceborne SAR systems were discussed. Both these approaches have very distinct purposes over each other and they have very specific uses. The combined simulator is a useful and feasible way of merging these two approaches to benefit from their advantages throughout the whole project cycle. The improvement and adjustment methodologies and appropriate interfaces are discussed for the currently available engineering simulator solution developed by STM, namely SARGUS. The performance and interface requirements between the two approaches are determined and guidelines for future work are outlined.

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