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A High-Level MultiFunction Radar Simulation for Studying the Performance of MultiSensor Data Fusion Systems

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ABSTRACT

This paper presents the basic requirements for a simulation of the main capabilities of a shipborne MultiFunction Radar (MFR) that can be used in conjunction with other sensor simulations in scenarios for studying Multi Sensor Data Fusion (MSDF) systems. This simulation is being used to support an ongoing joint effort (Canada- The Netherlands) in the development of MSDF testbeds. This joint effort is referred as Joint-FACET (Fusion Algorithms & Concepts Exploration Testbed), a highly modular and flexible series of applications that is capable of processing both real and synthetic input data. The question raised here is how realistic should the sensor simulations be to trust the MSDF performance assessment? A partial answer to this question is that at least, the dominant perturbing effects on sensor detection (true or false) are sufficiently represented. Following this philosophy, the MFR model, presented here, takes into account sensor's design parameters and external environmental effects such as clutter, propagation and jamming. Previous radar simulations capture most of these dominant effects. In this paper the emphasis is on an MFR scheduler which is the key element that needs to be added to the previous simulations to represent the MFR capability to search and track a large number of targets and at the same time support a large number of (semi-active) surface-to-air missiles (SAM) for the engagement of multiple hostile targets.

KEYWORDS: multifunction radar, simulation, sensor fusion, sensor integration

1. INTRODUCTION

The evolution of the air threat in maritime scenarios is characterized by very fast and highly maneuverable targets, a high target density, attack profiles from the horizon to high elevation angles, a reduction of the radar and infrared signature (stealth targets) and sophisticated jamming and deception techniques. In addition, there is a growing emphasis on maritime operations in littoral waters instead of the traditional open ocean or "blue water" environment. In littoral waters, the problems of anti-air warfare (AAW) are compounded by the large variety of weapons and weapon-carrying platforms that may be employed, e.g. fiber-optic guided missiles, short range ballistic missiles, helicopters, speed boats and fast patrol boats.

To meet this challenge, relying on a single stand alone data supplier system is in general prohibitively expensive since sensors capable of meeting such operational scenarios, and their associated threats, are complex and very costly as stand alone, autonomous equipment. Moreover, the performance of every single sensor system is limited by the physical laws underlying the sensor's operation and by environmental conditions. Therefore, to satisfy the extensive need for precise and timely information, and to overcome the existing limitations of individual single sensors, all available sensor sources must be used.

Major ongoing activities undertaken by the Decision Technology Section at Defence Research Establishment Valcartier (DREV) and the Observation Systems Division and the Maritime Platform Group at TNO Physics and Electronics Laboratory (TNO-FEL) are the investigation of sensor management, integration, and MultiSensor Data Fusion (MSDF) techniques that could apply respectively to the current Canadian and Dutch Frigates Above Water Warfare (AWW) sensor suite, as well as their possible future upgrades, in order to improve the frigate self-defense in challenging threat environments.

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The approach retained for that joint effort is to employ sufficiently representative sensor and phenomenological simulations combined with a judicious selection of representative data collected during well controlled experiments. Hence, a highly modular and flexible testbed is being developed as the result of the evolution of two existing testbeds: the DREV CASE_ATTI[1] (Concept Analysis and Simulation Environment for Automatic Target Tracking and Identification) and the TNO-FEL MT3[2] (Multiple Target Tracking Testbed). The resulting higher capacity testbed is hereafter referenced as Joint-FACET[3] (Fusion Algorithms & Concepts Exploration Testbed).

The new generation of air defence frigates has to be equipped with a high performance sensor suite to cope with the threat in future maritime scenarios. The NATO Anti-Air Warfare System (NAAWS) study developed a preferred sensor configuration to face the emerging aerospace threats to naval vessels. The stressing threats which drove the study were the subsonic seaskimmer (SBS), the supersonic seaskimmer (SSS), and the supersonic highdiver (SHD). The configuration consisted of a suite of four sensors which included:

- a volume search radar (VSR) for long range and high elevation air surveillance
- a multifunction radar (MFR) for horizon surveillance and fire control
- an infrared search and track (IRST) system for passive horizon surveillance
- a precision electronic warfare support measures (PESM) for the detection and classification of radar transmissions.

A multifunction radar (MFR) with a single rotating or multiple fixed phased array antennas is often the key element in this sensor suite because it can perform not only surveillance functions but also missile support. Since the MFR must be able to execute multiple functions concurrently, a scheduling mechanism is required that allocates the time and energy resources of the MFR to the radar functions in such a way that the overall performance of the sensor suite is optimized.

This paper presents the basic requirements for a simulation of the main capabilities of a shipborne MultiFunction Radar (MFR) that can be used in conjunction with other sensor simulations in Joint-FACET. This MFR model takes into account the sensor's design parameters and external environmental effects such as clutter, propagation and jamming. Previous radar simulations capture most of these dominant effects. In this paper the emphasis is on an MFR scheduler which is the key element that needs to be added to the previous simulations to represent the MFR capability to search and track a large number of targets and at the same time support a large number of (semi-active) surface-to-air missiles (SAM) for the engagement of multiple hostile targets. The paper is organized as follows. Section 2 gives a description of the MFR model. Section 3 presents the MFR scheduler and Section 4 gives an example of the results obtained with the MFR scheduler.

2. A MULTIFUNCTION RADAR MODEL

The purpose of this section is to determine the dominant factors that impact on the simulation of an MFR for data fusion studies. A number of environmental factors will have a significant impact on the MFR. These include surface clutter from both sea and land, along with a number of volumetric clutter sources such as returns from rain, flocks of birds, and chaff. Radar propagation will be dominated by multipath lobing. In addition, the MFR may be jammed in either the antenna mainlobe or in sidelobes. Since the MFR must be able to execute multiple functions concurrently, a scheduling mechanism is required that allocates the time and energy resources of the MFR to the radar functions in such a way that the overall performance of the sensor suite is optimized.

2.1 The MFR Functions

An MFR can perform many functions that are essential for the defence of an air space, but also functions that are not directly related to air defence such as navigation, surface search and tracking and support of shore bombardments. In this section, only functions are described that are directly relevant for air defence. The list of functions is expected to be representative of the next generation MFRs although some functions, in particular NCTR-functions, may be missing. Not all functions can be carried out at the same time due to the constraints of the time-energy budget. The allocation of time and energy to a function is therefore adapted to the tactical situation so that important functions and targets get a larger share of the time-energy budget.

Volume Search

The volume search function is used to detect air targets from just above the horizon to the maximum elevation that can be scanned with the phased array antenna (e.g. 70°). To minimize the load on the time-energy budget, the dwell time and data rate of the volume search waveform are tailored to the maximum instrumented range at each elevation. The volume search waveforms are in many cases chosen to be unambiguous in range which results in PRFs between 300 Hz and 5 kHz. The frame time is of the order of 5 to 10 seconds, depending on the instrumented range of the MFR. The scanning pattern may exhibit a random behaviour but the average time between two successive update in a certain direction is kept constant. Heavy loads on the time budget due to horizon search, target tracking or missile support may increase the frame time or even completely suspend the volume search function in some azimuth and elevation sectors.

Horizon Search

Sea skimmers are generally perceived to be the main threat for warships. Horizon search is therefore one of the primary functions of the AAW-sensor suite that is preferably carried out by an MFR because of its quick reaction capability. Severe requirements are imposed on an MFR to achieve a timely detection of fast targets with a small radar cross section (RCS) in an environment with clutter (sea, land, rain and chaff), anomalous propagation (ducting) and jamming. A large suppression of clutter and jamming and an insensitivity to ducting can only be met with a solid state transmitter (low peak power and high duty cycle), a large frequency agility bandwidth and an antenna configuration that supports either very low sidelobes, adaptive nullsteering or sidelobe cancellation. The preferred frequency band for horizon search is C or X-band. The PRF, dwell time and frame time that are employed for horizon search waveforms are very much dependent on the configuration of the radar. Typical values are a 10 kHz PRF, a 10 ms dwell time and a 1 s frame time. In addition to the detection range requirements, false targets, such as birds and insects, that have an RCS and velocity comparable with some stealthy targets (e.g., UAVs) must be rejected. The rejection of these false targets may claim a substantial share of the time-energy budget of an MFR if confirmation and track initiation dwells are used to start tracks on air targets.

Cued Search

The cued search function allows an air target to be acquired by the MFR under a designation by another sensor via the Command and Control System (CCS). The data provided by the external sensor concerning a target may consist of:

- azimuth, elevation and range (3-D radar),
- azimuth and elevation (IRST) or azimuth and range (2-D radar),
- only azimuth (ESM)

As soon as possible after the reception of a cue the MFR performs a search pattern until a target is detected that meets the search constraints. The search pattern takes into account the magnitude of possible manoeuvres, the target distance (if present), the accuracy of the cueing sensor and the width of the radar beam. The sensitivity of the MFR is improved compared to the normal (horizon or volume) search function by increasing the dwell length. In the event that the cueing sensor also provides the target speed, the acquisition of the target is faster and less time and energy of the MFR is spent.

Helicopter Search

The objective of the helicopter search function is to detect helicopters that are not detected with horizon search dwells due to the low radial velocity of the (hovering) helicopter body. The moving parts on the helicopter cause a modulation of the radar signal that may be employed to detect the helicopter even if the body is masked by clutter. The moving parts include the hub and the blades of the main and tail rotor. The spectral characteristics of the signal reflected by a helicopter when constantly illuminated with a coherent pulse Doppler waveform are:

- the helicopter body (body line) with a Doppler frequency that corresponds to the radial speed,
- the hub contribution with a triangular shape centred on the body line,
- a plateau of backscattered energy on both sides of the body line due to reflections of the rotor blade.

The detection of helicopters in a clutter background is possible due to the large RCS of the main rotor. This approach, however, requires a radar waveform with a dwell time that is long enough to contain at least one return of the main rotor blades (blade flash). Typical values of the dwell time required for blade flash detection are 100 ms. The PRF of the waveform must be high enough to ensure that at least one pulse is reflected by the rotor blades during the dwell time. In X-band, the duration of the flash is approximately 70 microseconds for a blade length of 5 m (even bladed rotor) and a rotation rate of 410 rpm. Typically, PRFs in excess of 20 kHz are needed for blade flash detection. Although the RCS of the hub is substantially smaller than the RCS of the rotors, hub detection is possible in favourable clutter conditions without the excessive requirements on dwell time and PRF for blade flash detection.

Air Target Tracking

The air target tracking function provides an automatic initiation and maintenance of air tracks. Air target tracking may be performed by transmission of dedicated track dwells or by a track-while-scan (TWS) method in which search dwells are used to update target tracks. Although dedicated track dwells increase the load on the time-energy budget, dedicated air tracking offers a better track accuracy due to the capability to adapt the data rate to the dynamical behaviour of a target. TWS and dedicated tracking may be combined in an MFR. MFRs generally employ monopulse to estimate the azimuth and elevation of a target.

Track initiation in an MFR is usually performed by transmission of a confirmation dwell after an alarm has occurred in a search beam. To reduce the problem with initiation of tracks on nuisance targets (and the concomitant load on the time-energy budget and processing resources), tracks are only initiated on targets with a certain minimum radial velocity. The dwell time and data rate of dedicated track dwells are tailored to the dynamic behaviour of a target so that the load on the time-energy budget of the radar is minimized. High update rates (up to 10 Hz) and/or long dwell times are used when a target starts maneuvering or when the accuracy of a track degrades due to multipath, jamming or clutter. The tracking waveform is adapted to the range and radial velocity of the target to avoid problems with eclipsing and clutter masking. Time and energy of the radar may be saved by performing tracking of multiple targets in an interleaved fashion, i.e. a single dwell is used to update the tracks of targets that have the same direction but a different range.

Missile Support

The level of support that is needed from an MFR for SAMs depends on the guidance mode. Homing-all-the-way semi-active missiles require that a target is continuously illuminated from the launch of the missile until intercept of the target. Since the MFR must also track the target in order to direct the illumination properly, the illumination waveform cannot be a continuous wave (CW) but must be either interrupted CW (ICW) illumination or a pulse-Doppler waveform. Typical values of the pulse length and PRF[1] of ICW-illumination are between 5 to 20 ms and 10 to 50 Hz respectively. Pulse-Doppler waveforms generally have PRFs of the order of 100 to 500 kHz and duty cycles up to 50%.

It will be clear that the load on the time-energy budget of a homing-all-the-way guidance mode is very high and that the multitarget capability is limited. To improve the capability of the AAW-system to engage multiple targets simultaneously with semi-active missiles, a midcourse guidance phase is used to direct semi-active missiles to their target. The MFR sends uplink messages to the missile[2] that may contain the position of the target and the missile (command guidance), the position of the target only (inertial guidance) or the angle and angular acceleration of the target with respect to the missile (command line-of-sight). The update rate and length of the uplink messages depends on the midcourse guidance mode, the dynamic behaviour of the target and the bandwidth of the uplink. The length of the uplink messages typically ranges from 1 to 100 ms while the update rate may vary from 10 Hz to no uplink messages at all (for inertial guidance) if the target does not manoeuvre. The duration of the terminal homing phase of the engagement may vary from 4 to 20 seconds, depending on the acquisition range of the seeker. A further reduction in the load of the missile support function on the time-energy budget of the MFR is obtained if a missile with an autonomous seeker (passive or active radar, infrared) is employed instead of a semi-active missile. Missiles with an autonomous seeker for terminal homing only require radar guidance during the midcourse phase of the engagement.

Non-Cooperative Target Recognition (NCTR)

NCTR is a secondary function of an MFR that supports the threat evaluation process in the Command and Control System (CCS). On designation of an operator the NCTR function is used to obtain more information about a target that is already in track. The MFR then provides a pre-processed radar signal to the CCS where target classification is carried out. The results

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[1] The pulse length and PRF of ICW-illumination are also referred to as dwell length and update rate, respectively.

[2] During midcourse guidance the main beam of the MFR is directed to the missile.

of different NCTR-techniques and several NCTR-dwells may be combined to achieve the desired confidence in the target classification. Four NCTR-techniques are possible:` HElicopter Rotor Modulation (HERM), the classification of helicopters is possible due to the modulation of the radar signal by moving parts of the helicopter; Jet Engine Modulation (JEM), feature extraction techniques for JEM use the spectrum and/or the cepstrum of the radar signal to estimate the number of blades on the compressor stage(s), the blade chop frequency and in some cases the number of engines; High Range Resolution (HRR), air targets can be classified on the basis of a high resolution profile of the backscattered radar signal along the line-of-sight; Inverse Synthetic Aperture Radar (ISAR), with the ISAR-technique, a high resolution profile of an air target can be obtained across the line-of-sight, i.e. a high resolution crossrange profile.

2.2 The MFR Model

A block diagram of the MFR is illustrated in figure 1 along with the interactions with Command and Control System (CCS) and the other sensors through a sensor integration function. Priorities are eventually sent to a sensor integration function for the scheduling and cueing of the appropriate sensors and data collection sources. This function, on the basis of an evolving picture and under the supervision of the overall CCS resource management, controls the information that the sensor data fusion system might receive by pointing, focusing, maneuvering, and adaptively selecting the modalities of the sensors and sensor platforms.

The sensor integration function is essentially concerned with the maximization of each individual sensor (e.g. MFR) output through synergistic cooperative work with the other members of the sensor suite and the shipboard combat system management to avoid (or at least minimize) inadvertent interference of one sensor system by another. Although such cooperative work is very important, the minimization of any system-to-system interference that may potentially result from the intrinsic nature of each sensor system is also essential to the success of a fully integrated military capability. Consider for example a modern radar system with a built in frequency agility feature and an Electronic Support Measure (ESM) system that are collocated on a ship. Without interference management, it could happen for a brief period that the radar radiates high power in a frequency band where the ESM is currently listening. This would produce catastrophic results. Techniques and procedures are thus required to ensure compatible operation of current and future shipboard sensor systems.

This paper addresses the simulation of the basic capabilities of a shipborne MultiFunction Radar (MFR) for studying multisensor data fusion (MSDF) algorithms. The approach retained is to employ sufficiently representative simulation of the dominant perturbing effects on sensor detection (true or false). A requirement for data fusion studies is that the MFR model can be used to generate contacts and false alarms in scenarios for MSDF studies while the scenario is running. Hence, measurements are then generated according to the probability of detection and the Signal-to-Interference ratio (*S/I*). In addition, the simulation generates false alarms as caused by clutter and system noise. The MFR model need to be used in conjunction with other sensor simulations.

The MFR model takes into account not only the sensor's design parameters but also the determinant factors affecting detection such as clutter, multipath, ducting, and the signal processing gain of the radar-environment-target chain by considering a Signal-to-Interference ratio (*S/I*). The *S/I* is used to evaluate the probability of detection, P_d, each time a target is geometrically hit by the radar beam. Measurements of range, azimuth and elevation of each target are then generated according to P_d and *S/I*. In addition, the simulation generates measurements (range, azimuth, elevation) corresponding to false alarms caused by clutter and system noise.

For various sets of weather conditions and radar characteristics, tables are computed to provide parameters or coefficients for the computation of:

- sea-clutter power and skewness;
- weather-clutter power;
- propagation factor;
- filters improvement factor;
- clutter-induced probability of false alarms.

These dominant factors have already been extensively described in previous shipborne radar simulations.$^{4\text{-}8}$ for data fusion study. This paper put emphasis on the MFR scheduler which is the key element that differentiate a conventional radar simulation from an MFR.

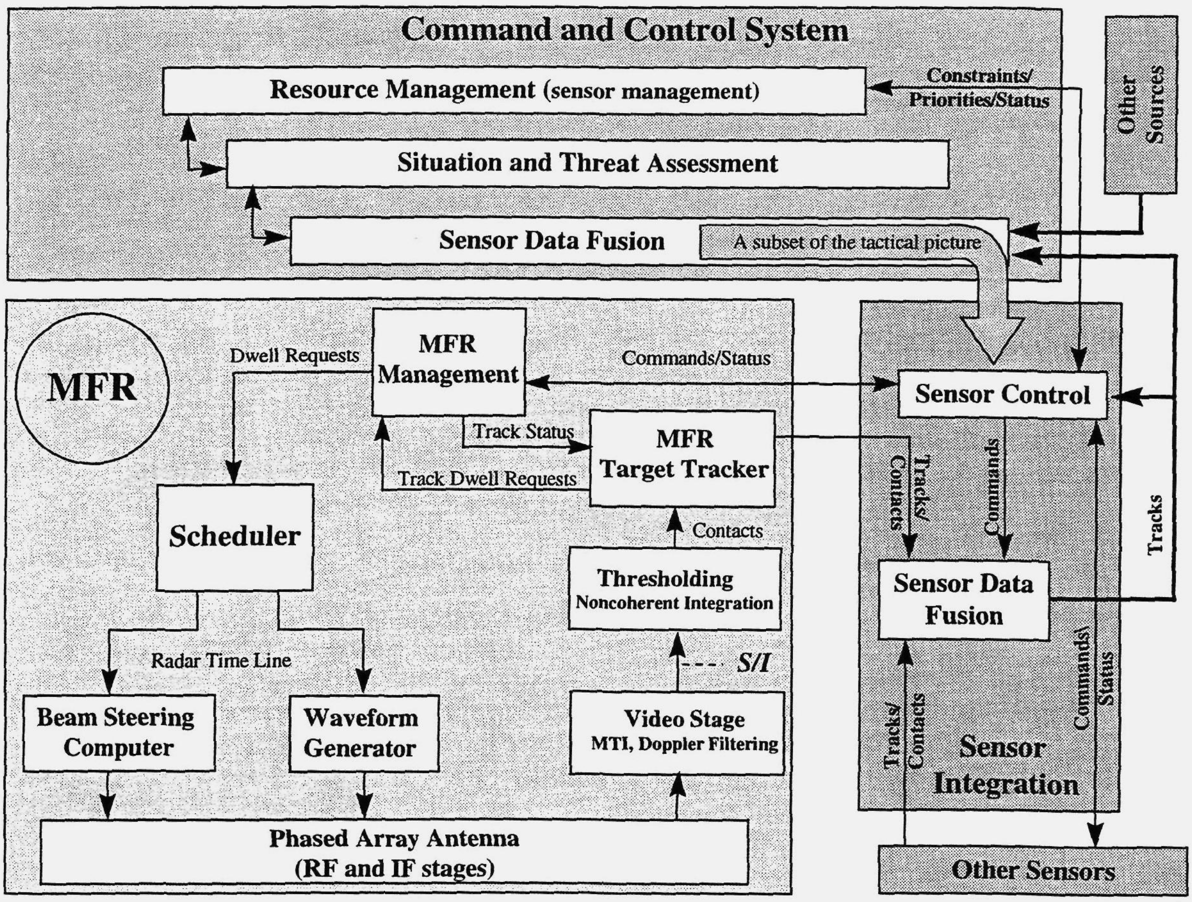

Figure 1: Block diagram of an MFR and its relationship with CCS

3. The MFR Scheduler

Since the MFR must be able to execute multiple functions concurrently, a scheduling mechanism is required that allocates the time and energy resources of the MFR to the radar functions in such a way that the overall performance of the sensor suite is optimized. Figure 2 shows a block diagram of the scheduler. Requests for transmission of dwells are generated by the radar management computer as a result of commands from the CCS or as a result of requests for track maintenance by the MFR target tracker. There are several types of dwell requests: search (horizon, cue), track (confirmation, air, weapon, SAM) and missile support (midcourse guidance, terminal illumination) dwell requests. Each dwell request contains an identification number, a priority, a dwell length, a transmission window that specifies the earliest, the desired and latest time of transmission, and the direction of the main beam.

Dwell requests that are submitted to the scheduler are placed in a list in which dwell requests belonging to the same frame are linked to the same branch. The branches with the dwell requests are ordered according to their priority; the dwell requests within a branch are ordered according to their desired time of transmission. Expired dwell requests (i.e. the current time is beyond the latest time of transmission) are removed from the list. In order of priority and the desired transmission time, dwell requests are placed in the dwell queue, if they satisfy the criterion that (i) the current time is within the transmission window and (ii) if the dwell length plus the length of the dwells that are already in the dwell queue does not exceed the maximum dwell queue length. If a dwell is placed in the queue, the dwell is unlinked from the dwell request list.

The maximum length of the normal dwell queue is determined by the requirement to have a short reaction time to requests for transmission of, for instance, cued search dwells and the requirement to allow for transmission of long dwells. The reaction time needed for cued search dwells can be derived from the requirement that the potential target is still within a half-a-beamwidth from the direction measured by the cueing sensor (e.g. the IRST-system).

Owing to the requirement for synchronous transmission, terminal illumination dwell requests are treated differently than other dwell requests. If a valid terminal illumination dwell request is found in the dwell request list (i.e. the current time is within the transmission window) then the whole frame of terminal illumination dwells is transferred to the terminal illumination dwell queue. If other terminal illumination dwells (for different targets) are already present in the terminal illumination dwell queue, the transmission time of the first dwell is delayed in such a way that multiple frames of terminal illumination dwells can be interleaved.

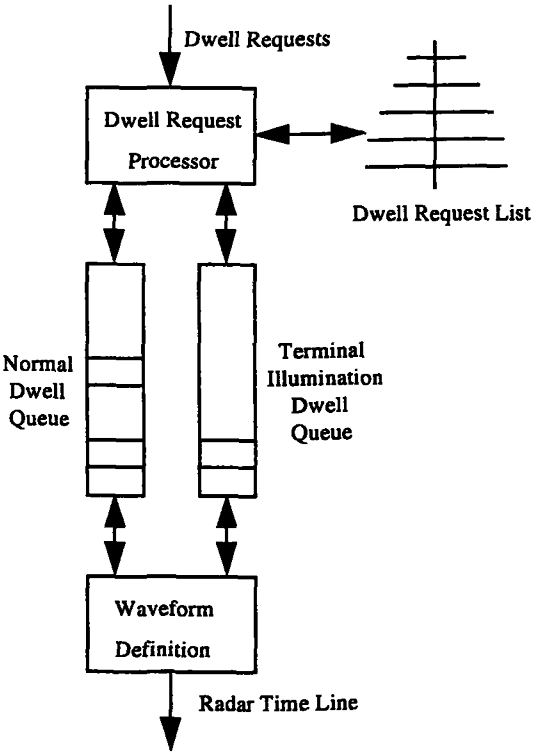

Figure 2: Block diagram of the scheduler

If there is a dwell in the terminal illumination dwell queue, the length of the normal dwell queue is adapted to the time that is available between successive terminal illumination dwells. This mechanism ensures that the time between the transmission of terminal illumination dwells is not changed due to the transmission of other dwells. When the terminal illumination dwell queue is empty again, the maximum length of the normal dwell queue is restored to its old value.

On the basis of their priority, a dwell is selected from the end of one of the two dwell queues and the remaining length of the dwell in the queue is reduced with a fixed time until the end of the dwell is reached. In this way room is created at the end of the dwell queue that becomes available for new dwells. After selection of a dwell, the waveform parameters of the dwell are determined. For radar dwells, the waveform parameters include the number of bursts, the carrier frequency, the pulse repetition frequency and the number of pulses per burst. For midcourse guidance and terminal illumination dwells the waveform is not pulsed but a continuous wave. A modulation that contains the uplink message is imposed on the continuous wave for midcourse guidance dwells. The result of this process is a radar time line that is sent to the beam steering computer and the waveform generator.

4. Example of an MFR Scheduler

An example has been developed[9] to illustrate the behaviour of the proposed scheduling algorithm in a given scenario. All the issues raised in the previous sections are not taken into account. Only some key properties have been simulated which are:

- only one antenna face is modelled so that the potential benefits of using the overlap between adjacent antenna faces is not taken into account,
- the trajectory of a target is specified by a number of time-tagged points on the trajectory,
- the radar detection of targets is modelled as a random process that uses the radar equation to determine the detection probability; the influence of antenna scanning losses, eclipsing and propagation (ducting) for low flying targets is taken into account,
- the effects of clutter, tracking errors and track loss are not modelled,
- an MFR-track is initiated after detection in a search and confirmation dwell,
- dwell requests are generated at a constant rate, except for confirmation and cued search dwells requests that are generated when a target has been detected in a search dwell or by the VSR or IRST. Furthermore, confirmation and cued search dwells are generated randomly with a given average rate to represent false alarms,
- the dwell lengths and transmission windows of all dwell types remain constant throughout the scenario,
- the sensitivity increase that may be required for cued search compared to the horizon search function is obtained by generating a rapid succession of horizon search dwell requests.

Function	Dwell Time	Update Rate	Window	Priority	Colour
Horizon Search (TI)	15 (6) ms	45 Hz	1000 ms	2	■
Confirmation (TI)	15 (6) ms	1 Hz	500 ms	3	■
Cued Search	6×10 ms	1 Hz	200 ms	4	■
Air Track	4 ms	50 Hz	200 ms	1	■
Weapon Track (KA)	4 ms	4 (10) Hz	100 ms	7 (8)	▨
Own Missile Track (KA)	2 ms	4 (10) Hz	100 ms	5	▒
Missile Acquisition	1 ms	10 Hz	100 ms	6	□
Midcourse Guidance	25 ms	1 Hz	100 ms	10	■
Terminal Illumination	5 ms	40 Hz	0 ms	9	░

Table 1: Dwell times, update rates and priorities for the radar functions

From a range of 34 km, four supersonic seaskimmers fly in a straight line towards the air defence frigate with a constant speed of Mach 3. The time between successive seaskimmers is 3.3 seconds. After the initiation of a track at a range of approximately 24 km and a reaction time of four seconds, a salvo of two semi-active SAMs is launched against each seaskimmer with an intra-salvo time of two seconds. After launch, a missile acquisition pattern is executed during a period of one second. The SAMs have an average velocity of Mach 2. The length of the terminal illumination phase is five seconds before and one second after the predicted intercept. Kill assessment is carried out during an interval that starts one second before and ends two seconds after the predicted intercept. In addition to the four seaskimmers, 100 air targets are present in the sector covered by the antenna face.

Table 1 shows the dwell times, update rates, transmission windows, priorities (a higher number means a higher priority) and colours (for the graphical representation of the schedule) assigned to the MFR functions that are active in the scenario. The update rate of the horizon search function is determined by the number of beams (45) required for a 90° sector and a frame time of one second. During the final phase of an engagement, the dwell time of the horizon search and confirmation function is reduced to allow transmission of these dwells in the interval between the synchronous transmission of terminal illumination (TI) dwells. Confirmation and cued search dwells due to false MFR and IRST-alarms are generated with an average of one per second. The cued search dwell is a sequence of six horizon search dwells in the same direction which increases the sensitivity of the MFR. The 100 air targets in the background are tracked with a update rate of 0.5 Hz which results in a total update rate of 50 Hz for the air target tracking function. The acquisition of a SAM is carried out by searching a sector that contains 10 beams. During kill assessment, the update rate of the weapon and SAM tracks is increased from 4 Hz to 10 Hz. The length of the normal dwell queue is equal to 100 ms when the terminal illumination function is not active. During the concurrent illumination of 1, 2, 3 or 4 targets the length of the normal dwell queue is reduced to 20 ms, 15 ms, 10 ms, 5 ms, respectively. Clearly, during the concurrent illumination of 5 targets no other dwells can be transmitted unless there is a valid higher priority dwell (e.g. a midcourse guidance dwell) present in the dwell request list.

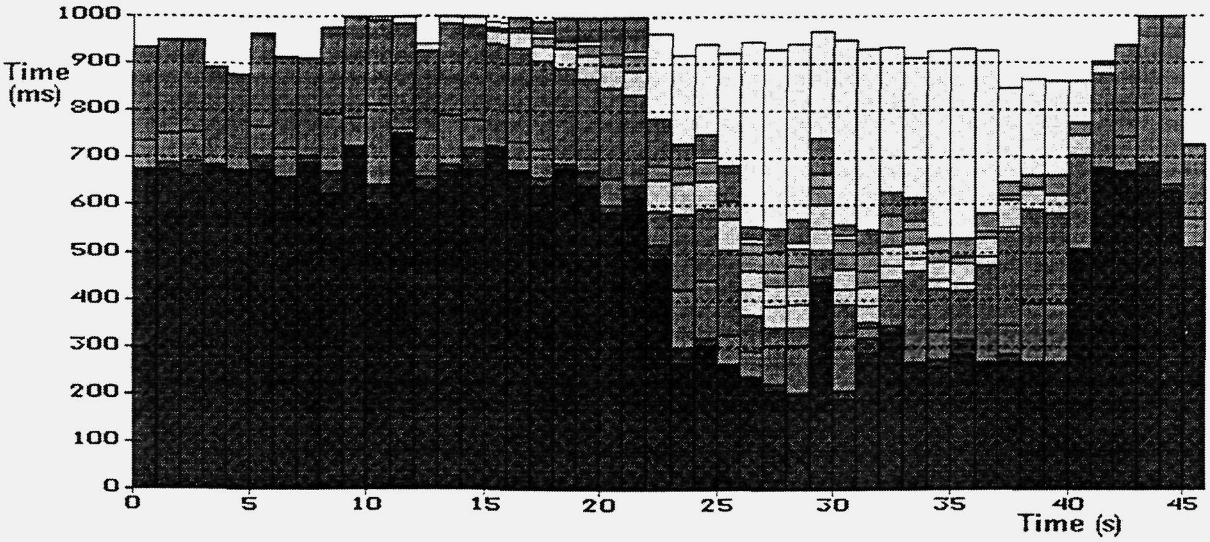

Figure 5: Histogram of the dwells transmitted during the scenario.

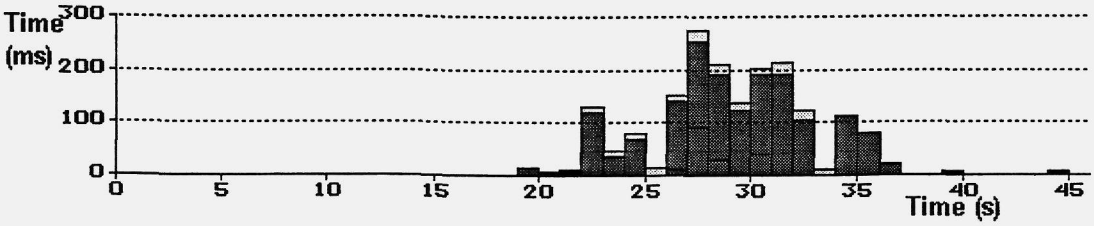

Figure 6: Histogram of the dwells that are not transmitted during the scenario.

The overall efficiency of the scheduling algorithm is clearly illustrated in figure 5 and 6 which show a histogram of the dwells that are transmitted and the dwells that are not transmitted during the scenario, respectively. It can be observed that a temporary overload of the time budget (e.g. from 9 to 12 seconds after the start of the scenario) is handled in such a way that dwells with a high priority are transmitted first and lower priority dwells (i.e. air track dwells) are delayed until there is room in the dwell queue. When the overload of the time budget occurs during an extended interval (starting from the 19-th second after the start of the scenario), low priority dwells are skipped because there transmission window is expired.

During terminal illumination, the time budget is not fully used because there are not always sufficient valid dwell requests available that fit between the terminal illumination dwells that have to be transmitted synchronously. The dwells that are not transmitted during terminal illumination of the targets are air track, cued search and terminal illumination dwells that are skipped in favour of the higher priority midcourse guidance dwells. More intermediate results are presented in reference [9].

5. CONCLUSIONS

This paper presented the basic requirements for a simulation of the main capabilities of a shipborne MultiFunction Radar (MFR) that can be used in conjunction with other sensor simulations in scenarios for studying Multi Sensor Data Fusion (MSDF) systems. The approach proposed was to represent the dominant perturbing effects on sensor detection (true or false). Since previous radar simulations detailed how to take into account sensor's design parameters and external environmental effects such as clutter, propagation and jamming, this paper emphasized an MFR scheduler which is the key element that needs to be added to the previous simulations to represent the MFR capability to search and track a large number of targets and at the same time support a large number of (semi-active) surface-to-air missiles (SAM) for the engagement of multiple hostile targets.

A scheduling algorithm has been proposed that manages the time and energy resources of an MFR in an efficient way. Dwell requests for each radar function are generated by the radar management computer and the scheduler places these dwell requests in the radar time line by using a simple queuing mechanism. In overload situations, dwell requests are rejected according to their priority and their transmission window that specifies the earliest, the desired and latest time of transmission. The reaction time of the scheduler to cues from other sensors is short due to the queuing mechanism. The scheduler permits the synchronous transmission of terminal illumination dwells and has only modest computational requirements. Simulations of the scheduling algorithm in a scenario with an engagement of multiple seaskimmers by semi-active surface-to-air missiles illustrated the approach.

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