SIMULATION METHODS FOR PRIORITISING TASKS AND SECTORS OF SURVEILLANCE IN PHASED ARRAY RADARS

S.L.C.MIRANDA, C.J.BAKER, K.WOODBRIDGE, H.D.GRIFFITHS

Department of Electronic and Electrical Engineering
University College London
Torrington Place, London, UK - WC1E 7JE
s.miranda@ee.ucl.ac.uk , c.baker@ee.ucl.ac.uk , k.woodbridge@ee.ucl.ac.uk, h.griffiths@ee.ucl.ac.uk

Abstract: Multifunction phased array radars have the ability to steer the radar beam electronically, adapting its parameters according to how the radar perceives the environment. Thus, the effective allocation of available resources is very important. A model of a multifunction phased array radar is implemented to examine the complex problem of resource allocation in this type of radar. Additionally, approaches to adaptively assigning priorities of targets and sectors of surveillance are developed and assessed. Ranking radar tasks is an important sub-problem for radar resource management. When the radar resources are not sufficient to undertake all radar functions, the function priorities will indicate an appropriate manner of reallocating these resources. In this paper, simulation methods to evaluate prioritisation of tasks are described.

Keywords: radar simulation, multifunction radar, priority assignment.

1. INTRODUCTION

Phased array antennas have matured rapidly in recent years and this technology is set to become the norm in complex and advanced radar systems. The ability to steer the radar beam electronically is highly desirable as the reaction time is faster than in traditional mechanically steered radars. This allows a combination of functions, such as tracking, surveillance and weapon guidance, which were traditionally performed by dedicated individual radars. This new type of radar is called multifunction radar.

A phased array multifunction radar has a high degree of adaptability and is able to adapt beams as a result of knowledge acquired from the scene under interrogation. This knowledge has a high level of uncertainty, and hence we have a poorly posed problem for a control loop that contains many variables. This leads to a challenging simulation problem. For example, having many tasks to perform, the multifunction radar has to make a decision as to which functions are to be performed first and which must be degraded or even not done at all when there are not enough resources to be allocated. The process of making these decisions and determining their allocation as a function of time is known as radar resource management (RRM).

In this paper, we present simulation methods that were used to analyse and understand the radar resource management issue in naval applications. In particular, we develop a multifunction phased array radar model and compare adaptive priority assignment methods to fixed task priority schemes in changing tactical scenarios. In radar resource managers, a prioritisation module will have a close relationship with the scheduling function. This scheduling function has to consider a number of constraints such as time and energy in order to maximise the number of tasks that are able to meet their desired deadline. Ranking radar tasks is an important sub-problem for radar resource management. It not only contributes to an efficient scheduling process by defining which conflicting tasks are going to be delayed, but also influences overall resource allocation by determining the tasks that will not be performed in overload conditions.

Although functional simulations of multifunction radar systems involving scheduling and task ranking may give some insights into their overall effects on resource allocation and radar system performance, only a few reports have addressed this subject [Orman et. al, 1998; Watson, 2002]. However, there have been a number of reports in the literature examining resource management from the perspective of the design of efficient scheduling algorithms, using neural networks, Operations Research (OR) theory and related techniques [Izquierdo-Fuente and Casar-Corredera, 1994; Strömberg and Grahn, 1996; Orman et al., 1996]. In addition, few reports have analysed target ranking by using either neural networks or fuzzy logic. These methods have the advantage of making softer or slower decisions and hence not re-assigning resources instantly if not absolutely required [Molina Lopez et al., 1998; Komorniczak et al., 2000, 2002; Vine, 2001].

This paper is organized as follows. Initially, section 2 describes the architecture of the simulation used in the analysis. Next, section 3 presents the earlier implementations of the radar model and some results of a comparison of two scheduling algorithms described in the literature. In section 4, methods of prioritising tracking and surveillance tasks are examined, using fuzzy logic techniques. The preliminary results of this examination are presented in section 5, and section 6 gives some concluding comments.

2. DESCRIPTION OF THE SIMULATION ARCHITECTURE

Considering that there are several possible approaches to address radar resource management, a simulation model of a multifunction phased array radar was developed to provide a better understanding of their effects on the final allocation of the radar resources and on the radar performance.

The present work considered the behaviour of one face of a multi-face phased array antenna radar system. For simplification, the study included radar functions of both surveillance and tracking.

The architecture used in the radar model is presented in figure 1. It provided an environment in which different radar resource management techniques could be represented and examined against any given operational scenario. The radar model was developed using MATLAB. A modular approach was used in developing the simulation model. The advantage of this modularity was that comparisons of different approaches could be performed keeping other radar parameters fixed. The approaches were compared under the same initial conditions and the same tactical characteristics in respect to targets and environment.

The purpose of using this architecture was to obtain a better understanding of the sensitivities of the control parameters involved in different resource allocation methodologies. This aspect is particularly useful when analysing ill-defined problems, such as RRM.

The main blocks are briefly described in the following:

2.1 Scheduler

The scheduling algorithm is responsible for effectively assigning a set of measurement tasks to the multifunction radar considering resource constraints, such as time and energy. To achieve the required function performance, all the measurement tasks requested by the radar functions must have deadlines assigned to them. Therefore, the scheduler must create a list of tasks to be performed by the radar, maximising the number of tasks that meet their deadlines.

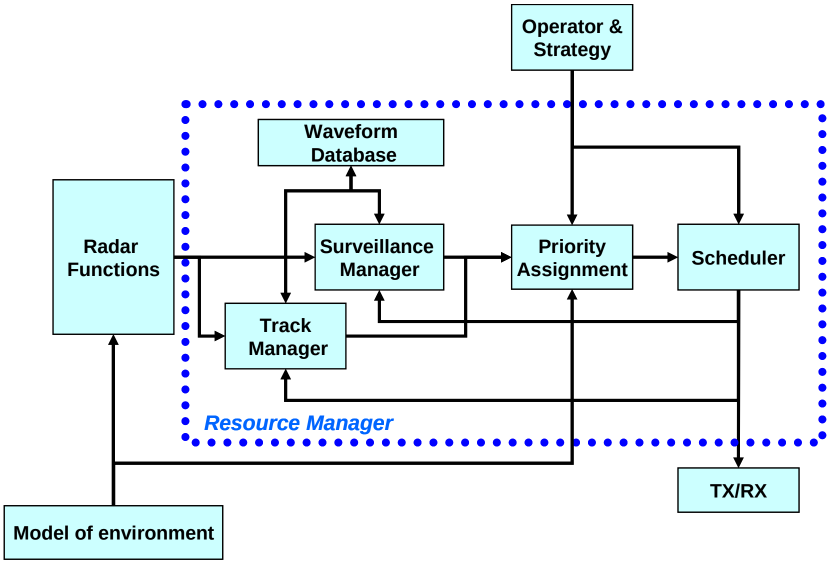

Figure 1: Block diagram of the simulation architecture used in the comparison

2.2 Priority Assignment

This block assigns degrees of importance to the tasks that must be executed by the radar. Several factors may be taken into consideration when evaluating the task priority, such as evolution of the environment, nature of the task (surveillance, tracking and weapon guidance), degree of threat of the tracked targets, etc.

2.3 Surveillance Manager

This function maintains a queue of unscheduled surveillance tasks and provides the scheduler with a smaller list of task requests that are close to their due times of execution. It also selects the parameters of the waveform to be used in the transmission of the radar pulses, in order to meet the requirements of surveillance performance.

2.4 Track Manager

Like the surveillance manager, it keeps a list of unscheduled track requests, sending them to the scheduler when appropriate. The track requests are generated by the tracking process associated with each target, which determines the next desired update time, the time allocated to the measurement process (dwell time) and the position of the radar beam for the measurement, in order to achieve the requirements of tracking performance.

2.5 Radar Functions

Two radar functions are represented in this case of study. Firstly, the surveillance function is responsible for creating a list of radar task requests, corresponding to radar beam positions that must be looked at in order to maintain the required detection performance over a radar coverage area. Lastly, the tracking function calculates the predicted positions of the tracked targets, considering their previous position measurements and the related position estimation errors. The output of the tracking function is a list of update requests for all tracked targets. In this work, adaptive Kalman filters were used for each target.

2.6 Operator and Strategy

Two aspects are accounted for in this block. The first is the overall strategy for resource allocation. This is externally provided to the system and is determined by the radar mission. The other is the decision of the operator to modify automatic allocations based upon his/her own evaluation of the tactical scenario.

3. EARLIER IMPLEMENTATIONS

The radar model developed in this work was already applied to address the comparison of different scheduling approaches described in the literature [Miranda et al., 2004]. The algorithms are presented in [Orman et al., 1996; Butler, 1998]. Both algorithms were codified and used in the simulation architecture presented in figure 1. Several load situations were considered to allow the evaluation of their behaviour in different environments, when there may or may not exist enough radar resources to maintain the required performance for all radar jobs. The results indicated that although very different in implementation, the scheduling algorithms showed broadly similar performance in respect of the ability of both planning the radar task timeline and scheduling tasks as close as possible to their due time of execution. The analysis was done under the same test conditions for both algorithms.

Figure 2 shows the results of a simulation in which the radar coverage was divided into three sectors of surveillance. Initially, it was assumed that no target was detected. Thus, only surveillance tasks were performed and the radar load in each sector was determined by the required detection performance, as there were available resources to perform surveillance. After a few seconds, several targets were progressively detected and, as the target tracking function had a higher priority than the surveillance function, the detection performance was gradually degraded.

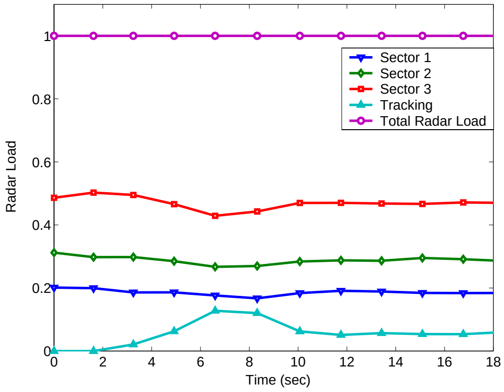

Figure 2: Radar load resulting from the use of the Butler type scheduling algorithm

To understand the effect of the required surveillance on the radar load, two surveillance parameters must be defined: frame time and function time. Frame time is the time over which the surveillance of a sector is made, and function time is the sum of all beam dwell times in a given surveillance sector [Billeter, 1989]. The ratio of function time to frame time is the surveillance load of the sector. Both frame time and beam dwell time are factors that determine the surveillance performance of radars. When the radar time resources are being extinguished, two possible solutions to degrading surveillance performance are: either decreasing beam dwell times or increasing frame times. In both cases, the final surveillance load is decreased.

Figure 3 shows the performance of the same algorithm when planning the execution of tracking tasks. In order to better use the radar timeline, some tasks were scheduled either earlier or later than their due times. However, this effect was not relevant in respect to the performance of the tracking function. Earliness and lateness of tenths of milliseconds are not significant when scheduling tracking tasks, as there are usually greater errors considered when estimating the position of targets.

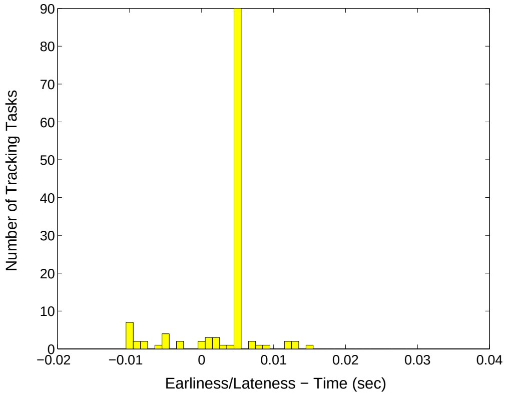

Figure 3: Number of Tracking Tasks x Earliness/Lateness when using the Butler type scheduler

4. PRIORITISING RADAR TASKS

Examination of the results from the previous comparison suggested that an important method to investigate radar resource management was to develop an adaptive prioritisation assignment for both tracked targets and sectors of surveillance.

In typical naval applications, different sensors coexist with a multifunction radar in the same platform. The idea of the prioritisation approach was to use information provided by these sensors to assess the importance of a given radar function with higher accuracy. For example, the identity of a target can be inferred by using an IFF system or even the multifunction radar itself operating in high resolution mode. It is reasonable to consider that, in some situations, few radar resources should be spent tracking friendly targets at high range than looking for new targets in a surveillance sector where an increasing number of threatening targets is being detected. Thus, as the tactical environment evolves, the radar task priorities should be adaptively reassigned, resulting in a continuous reallocation of the radar resources.

This paper examines two different approaches for prioritising tracking and surveillance functions, using fuzzy logic techniques.

4.1 Prioritising tracking tasks

The priority of tracking targets was evaluated using the decision tree presented in figure 4, according to information provided by a tracking algorithm, by other sensors, or by other operation modes of the multifunction radar, such as a high resolution mode. The tracking algorithm is part of the tracking function described in section 2.5. Five different variables provided information concerning the degree of threat, hostility, quality of tracking and relative position of the target, and weapon system capabilities of the platform. Fuzzy values were attributed to each variable. Some examples of the fuzzy values are presented in table 1. After evaluation of these variables according to a set of fuzzy rules, the importance (priority) of the target was determined.

Fuzzy Variable	***Fuzzy Values***
Priority	Very Low, Low, Medium Low, Medium, Medium High, High, Very High
Hostile	Non-hostile, Unknown and Hostile
Weapons Systems	Low, Medium and High priorities
Threat	Very Low, Low, Medium Low, Medium, Medium High, High and Very High
Position	Close, Far, Medium

Table 1: Examples of fuzzy variables used in the assignment of priorities for targets

4.2 Prioritising surveillance tasks

A similar methodology was applied to the surveillance function base upon the decision tree presented in figure 5. In this case, the priority of surveillance sectors was assessed through the original priorities attributed to the regions with respect to the expected tactical scenarios and the information gathered during the evolution of the actual environments. This included aspects such as rate of detection of new targets, number of threatening targets and rate of detection of new threatening targets. A set of fuzzy rules enabled the evaluation of the priority of the different sectors considered for surveillance.

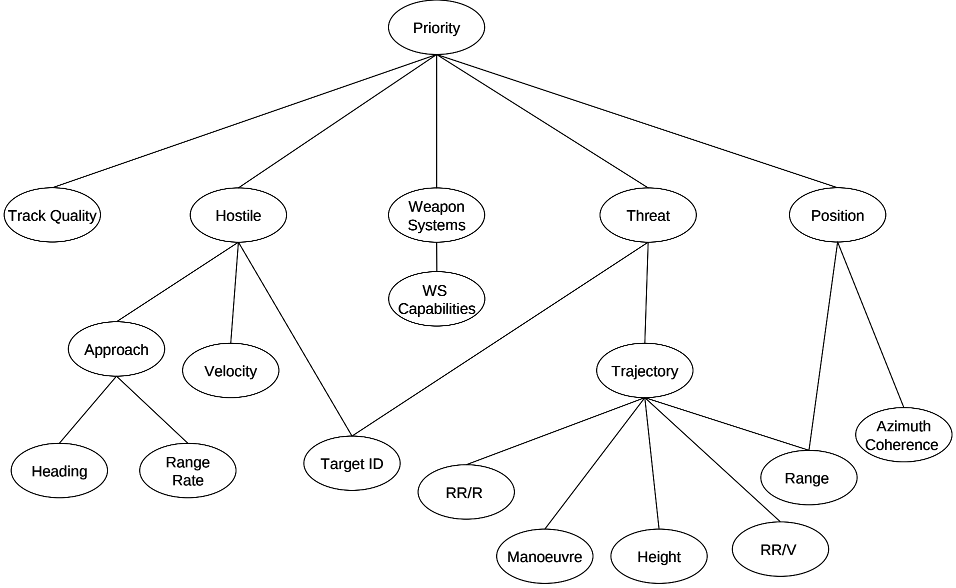

Figure 4: Decision tree for target priority assessment

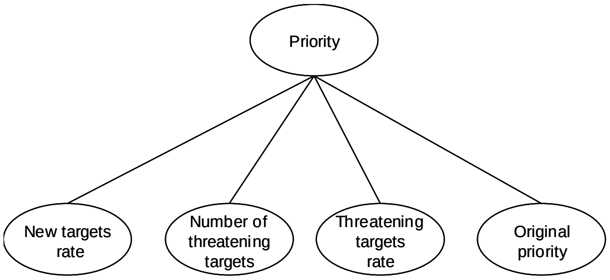

Figure 5: Decision tree for sectors of surveillance priority assessment

5. RESULTS

Initial simulation results of the prioritisation approaches presented in the previous section are showed in figures 6 and 7. The aim of the simulation was to evaluate the effects in resource allocation and radar performance, when using both fixed priority assignment systems and the fuzzy reasoning priority approaches presented in this paper.

Figure 6 presents the priority evolution of three aircraft moving along the same straight line trajectory towards the radar platform. Each aircraft has a different degree of threat. In this case, the first aircraft was identified as an enemy target, the second was surely a friendly target, and the last was not identified, being considered an unknown target. Therefore, their degrees of threat were assessed as high, very low and medium, respectively. The results showed that the higher the degree of threat of a target, the greater its priority will be. This aspect is particularly important in overload situations where there are insufficient resources to perform all the requested tasks and the resource manager must decide which of the radar functions will be degraded.

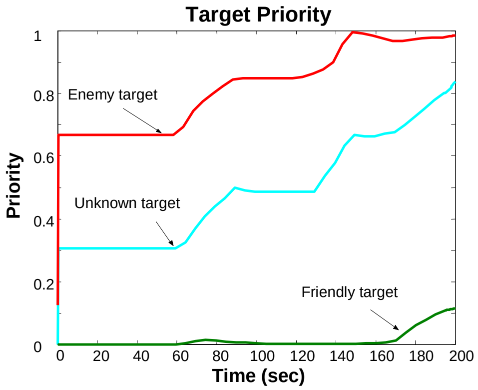

Figure 6: Priority evolution of targets with different threat degrees, moving along the same trajectory

In addition, figure 7 shows the adaptive prioritisation of a sector of surveillance when using the fuzzy approach proposed in section 4.2.

At first, it was assumed that there were no detected targets in the sector under observation. Gradually, targets moved into the sector and were detected. Subsequently, their degrees of threat were evaluated according to the method presented in figure 4. The combination of the original priority of the sector with the number of threatening targets and the total number of targets detected in the sector provided an evaluation of the importance of the surveillance tasks in that sector.

In the fixed task priority scheme, the original task ranking does not evolve even though the environment is changing. In the analysis presented here, the priority order in table 2 was used as reference. Figure 8 shows the results of the simulation of an overload situation using this priority order. We considered a region of coverage spanning from -45º to +45º away from the antenna's broadside and divided this into three different sectors. As the amount of available radar resources was extinguished, the performance of lower priority functions was degraded to the point that no surveillance performance at all was achieved in some sectors.

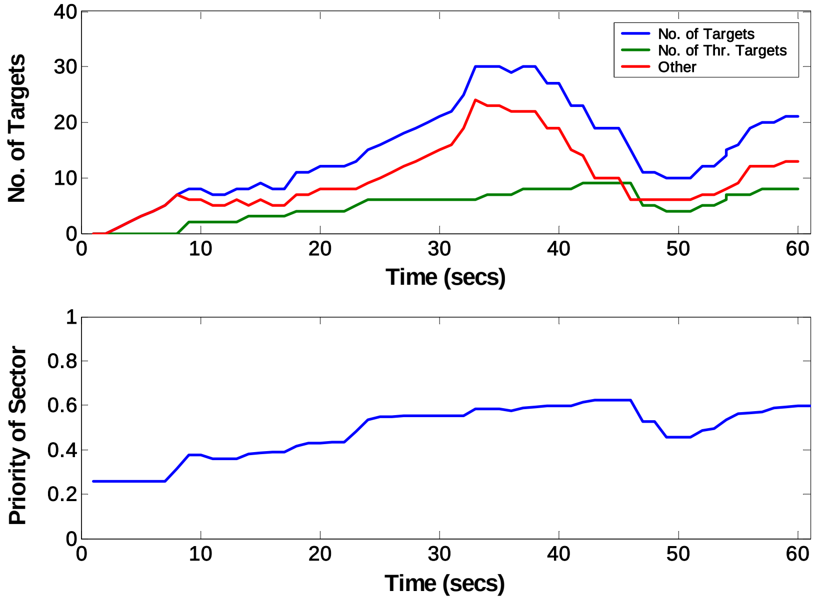

Figure 7: Evolution of the priority of a surveillance sector when the tactical scenario is varying over time.

Priority	***Radar Task***
1	Track maintenance
2	Plot confirmation
3	Track initiation
4	Track update
5	Surveillance
6	Auxiliary tasks

Table 2: Radar task ranking order

6. CONCLUSION

In this paper, we have described a viable simulation strategy that copes with an ill-defined control loop problem, where many variables are present. This has been achieved by making a number of simplifications in the representation of the environment as seen by the radar. This has then allowed a comparison of different resource management techniques.

The functional simulation of a multifunction radar presented here provides important insights into the resource management issue. The simulation proved useful when analysing the performance of different scheduling algorithms. Although different techniques were used in the design of the algorithms, the results showed that their overall performance was broadly similar.

The analysis of an overload situation similar to the one showed in figure 8 will be done, considering the priority assignment approaches presented in this work. The initial results suggest that the fuzzy approximation is a valid means to evaluate the relative importance of targets and sectors of surveillance. By assessing the priorities according to a set of rules that imitates the human decision-making process in a similar tactical situation, the resource manager can distribute the radar resources in a more effective way.

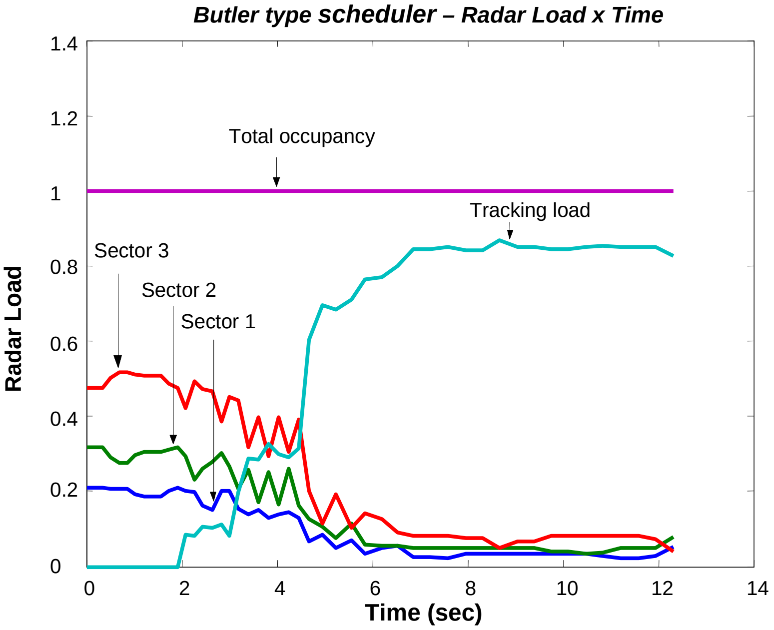

Figure 8: Results form the simulation of an overload situation using a fixed priority scheme in which tracking tasks prevail over surveillance tasks.

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Hugh Griffiths is Head of the Department of Electronic and Electrical Engineering at University College London, England. He received the MA degree in Physics from Oxford University in 1975, then spent three years working in industry, before joining University College London, where he received the PhD degree in 1986 and the DSc(Eng) degree in 2000. His research interests include radar and sonar systems and signal processing, and antenna measurement techniques. He has published over two hundred papers and technical articles in the fields of radar and antennas. In 1996 he received the IEEE AESS Nathanson Award (Radar Systems Panel Award). He is a Fellow of the IEE, Fellow of the IEEE, and in 1997 he was elected to Fellowship of the Royal Academy of Engineering.

Karl Woodbridge obtained a BSc in Physics in 1976 and a Ph.D in Materials Science from the University of Sussex in 1979. He is a chartered engineer and a member of the IEE and IOP. He joined University College London in 1990 after 10 years working for Philips Electronics latterly as a principal research scientist and project manager in the semiconductor electronics area. Current radar research activities at UCL include multifunction, narrowband, bistatic and netted systems for a variety of customers in both civil and defence related areas. The above activities have generated over 140 journal papers and conference presentations.

Chris Baker is Professor of radar research within the Electronic and Electrical Engineering Department of University College London. He has been actively engaged in radar system research since 1984 and is the author of over seventy publications. His research interests include, Coherent radar techniques, radar signal processing, radar signal interpretation, Electronically scanned radar systems and radar imaging. He is the recipient of the IEE Mountbatten premium (twice), the IEE Institute premium and is a fellow of the IEE. He is also currently chairman of the IEE Radar, Sonar and Navigation systems professional network.

Sérgio Miranda is a Brazilian Navy Officer who obtained a BSc in Naval Sciences with a major in Electronics from Escola Naval (Brazilian Naval Academy), Rio de Janeiro, in 1992 and a BSc in Electrical Engineering from University of Sao Paulo in 1997. After almost 5 years working at a dockyard of the Brazilian Navy in the area of repair of electrical machines and control devices of ship propulsion systems, he started in 2002 an MPhil programme at University College London. His research work focus on resource management of naval multifunction phased array radars.