Multistatic and Networked Radar: Principles and Practice

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Abstract— **Professor Viktor Chernyak was a visionary whose book *Fundamentals of Multisite Radar Systems*, published in 1993, set out the principles of multistatic and multiradar systems. This paper summarises Chernyak's contribution, provides some historical background to the development of networked radar, and discusses the technical issues that will be necessary for practical networked radars to be feasible in the future.**

***Keywords*— Bistatic radar, multistatic radar, radar networks**

I. INTRODUCTION

Professor Viktor Chernyak (Fig. 1) was a visionary whose book *Fundamentals of Multisite Radar Systems* [1], published (in Russian) in 1993, set out the principles of multisite radar. The book was translated into English and published in 1998 [2] (Fig. 2), and ever since has had a profound impact on the development of bistatic radar systems worldwide.

Professor Chernyak passed away on 15 March 2020 at the age of 91. He was a Professor at the Scientific Research Institute of Radio Device Engineering (NIIRP) in Moscow. He was a member of the Scientific Council on Statistical Radiophysics at Russia's Academy of Sciences, and was Head of the regular Symposium on Multistatic Radars and Multiradar Systems. He is survived by his wife, Nina, and his son Sergey, who said that he 'lived a long, bright and happy life, was a true scientist, a wonderful friend, wise, kind, loving and noble man'.

The purpose of this paper is to provide an introduction to a Special Session on Multistatic and Networked Radar.

Figure 1: Professor Viktor Chernyak.

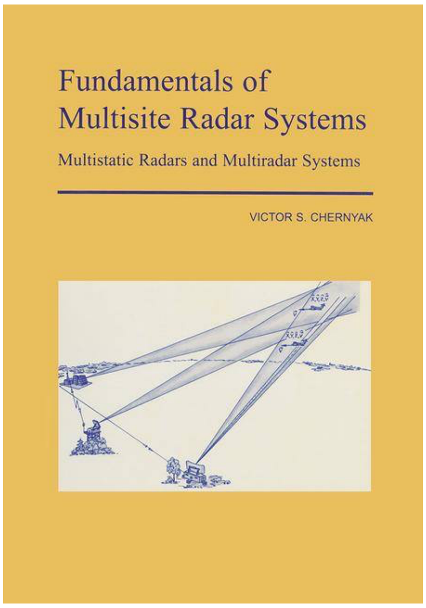

Figure 2: *Fundamentals of Multisite Radar Systems*.

II. HISTORY OF BISTATIC RADAR [3]

The history of bistatic radar goes back almost as far as that of radar itself, partly because some of the earliest observations of the radar effect were of the disturbance of signals on communications links caused by moving targets, and partly because until the invention of the transmit/receive switch it was necessary to use separate transmit and receive antennas. Some of the earliest experimental radars, in several countries, took the form of forward scatter fences, and we can note Appleton and Barnett's experiment in 1935 to measure the height of the ionosphere, and the celebrated Daventry Experiment in 1935 as important examples [8].

Another remarkable bistatic radar from this time was the German WW2 *Klein Heidelberg* system, which used transmissions from the British Chain Home radars as their illumination source [7, 8, 10]. Six Klein Heidelberg stations were built, in France, Belgium and The Netherlands. Since they emitted no signal of their own, and used existing Wassermann antenna towers and bunkers, they were essentially undetectable, and the British did not find out about them till November 1944 from interrogation of a captured German radar operator [7]. The maximum reported detection range was ‘usually about 450 km each day’ – which is certainly impressive. However, several of the sites did not reach operational status, and some were destroyed by Allied air attack in the weeks leading up to D-Day, so the operational effect of Klein Heidelberg was limited. Nevertheless, it can claim to be the first operational use of bistatic radar, and was certainly decades ahead of its time.

Interest in bistatic radar lay largely dormant after WW2. Willis [3] has remarked that there were periodic resurgences in interest [14], but in each case they receded once the true difficulties were realised. It was not till the 1990s (the ‘third resurgence’) that the advantages of bistatic radar began to outweigh the disadvantages, and that technology was available to address aspects that had previously been insoluble.

Some of the advantages of bistatic radar are as follows:

- Bistatic radar has potential advantages in detection of stealthy targets which are shaped to scatter energy in directions away from the monostatic
- The receiver is covert and therefore safer in many situations
- Countermeasures are difficult to deploy against bistatic radar
- Increasing use of systems based on unmanned air vehicles (UAVs) makes bistatic systems attractive
- Many of the synchronisation and geolocation problems that were previously very difficult are now readily soluble using GPS, and
- The extra degrees of freedom may make it easier to extract information from bistatic clutter for remote sensing applications.

III. The Intelligent Adaptive Radar Network [4, 9]

We argue that the radars of the future will be different to the single-platform monostatic systems that have hitherto been the norm, and this was foreseen by Chernyak. These are inflexible (the platform can only be in one place at once) and they are vulnerable (if the platform is taken out, the whole capability is lost). Rather, a sensing capability based on a radar network has some significant attractions.

A radar network is inherently flexible, so it can be dynamically configured to optimise its coverage and performance (Fig. 3). If a node is lost, the network can dynamically be reconfigured to restore the performance. The network may include receive-only nodes that are completely passive, and it may exploit broadcast and communications signals as well as co-operative illuminators. Also, fundamentally, the different nodes provide extra information over a purely monostatic configuration, giving the potential for improved detection and tracking.

However, there are some difficult problems to be solved before such a network can be realised, including the means of communication between the nodes (especially in the presence of interception, interference and jamming), the resource management of such a network (centralised or distributed, or some sort of combination, and probably using cognitive approaches), and Position, Navigation and Timing (PNT), so that the location of each node of the network is precisely known, and there is a common timing and phase reference across the network. Research into these issues is being vigorously pursued, in several countries.

These developments are mentioned also on p7 of reference [2]: ‘In the last years much attention was paid to different MSRSs with moving baselines. It is associated with noticeable achievements in precise radio navigational techniques and systems, data transmission and accurate synchronisation of remotely located facilities’.

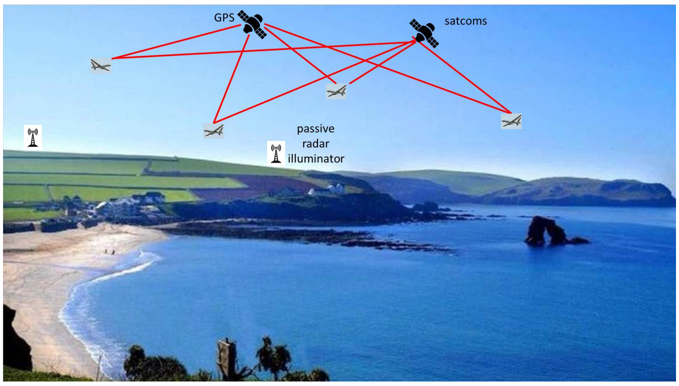

Figure 3: A sketch of the intelligent adaptive radar network. In this example there are four airborne nodes and communication and control of the network is via satcom links. This network also exploits passive radar illuminators [9].

A particularly visionary publication in this subject was provided by Dr M. Wicks, in a keynote presentation at the 2003 International Radar Conference in Adelaide, Australia, entitled ‘Sensors as Robots’ [6]:

> *A … scout troop is charged with cleaning the town park. Initially, each boy is assigned a specific task and timeline. However, soon into the exercise, and as a result of some minor and perhaps major situational changes, the original individual marching orders are modified, or perhaps even ignored, on the fly. In any event, however, each member of the troop does his part to accomplish the goal of cleaning the park. In the end, the mission is successfully completed. Independent entities (the Scouts) have operated in an autonomous manner using cognitive reasoning in responding to real-time changes in the environment, to accomplish a preassigned mission. The individual Scouts, by sensing the behavior and activities of their colleagues in response to the changing environment, and by communicating the necessary data and information, achieved a collective response that resulted in a “successful” operation. This “system” worked as a result of the autonomous and intelligent interaction between the individual “subsystems”.*

This analogy is compelling. The individuals act autonomously, but perceive the target scene and the progression of the operation, and can communicate with each other. They may modify their intended tasks on the basis of this information.

IV. DETECTION, TRACKING AND FUSION IN MULTISITE RADAR SYSTEMS

The book [2] is amazing in its detailed technical description. The book is organised in 15 chapters, 60 sections (each one diligently closing with a summary for the sake of reader), 270 references, an index of about 200 entries and a list of abbreviations. The number of figures and equations is outstanding. The discussion of target detection is in the seven chapters of Part II of the book; the companion pivotal topics: target coordinate estimation and tracking are the subject of five chapters of Part III of the book. These themes have been the subject of R&D of the authors of the present paper. Detection in multistatic radar systems is echoed in some references [12, 13], whereas target position accuracy is addressed in [11]. Tracking in bi-multistatic radar is reviewed in [16], with some more recent application to passive multistatic radar in [15]. Estimation accuracy is widely and detailed calculated in several study cases in Prof Chernyak book. It can be related to [17] where the theoretical estimation accuracy - the Cramer-Rao bound - is exploited to suitably select the pairing of transmitter-receiver channels in a multistatic radar system as the targets/s travel along paths: a kind of adaptation of the system architecture netting in relation to the target motion. The detailed mathematical analysis goes hand in hand with engineering considerations. Quoting from [2] at p. 30: "In the late of 1970s MSRS with information fusion at a track level where employed … for ATC systems in Europe. …Creating such MSRSs with "multi-radar tracking" *was a result of the systems' development.*[1]" Pros & cons are a leitmotiv in the book. Hardware and software implications with cost considerations are related to the multisite architectures. This brings into the scene the error budget of data fusion process (Fig. 4).

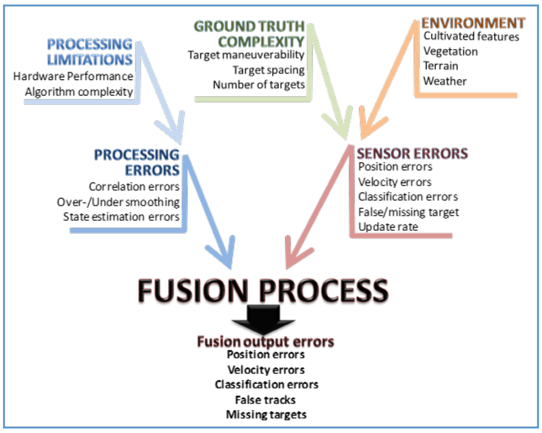

Figure 4: Fusion system error budget [18].

V. A TECHNOLOGY FOR THE XXI CENTURY

The general trend in surveillance today is towards the concept of "Network Centric Operation" (NCO). The vision for NCO is to provide seamless access to timely information to all operators (soldiers, officers and so on) and decision-makers at every echelon in the defense and organisational hierarchy. The performance achieved by the software and technology systems is fully ready to develop such systems by the design of service oriented architectures. The goal is to enable all elements, including individuals, ground vehicles, command centres, aircraft and vessels, to share the collected information and to combine it into a coherent, accurate picture of the surveilled scenario.

To gain more surveillance capability, wireless sensor network without a global fusion centre appears to be a crucial subject to consider. The scope is to achieve a global detection/estimation/localization through localized processing alone, so that the final estimation/decision is available for each node in the network [18].

This approach is strongly advocated for its robustness and relatively ease of implementation. It has a broad range of potential applications: homeland security, surveillance of habitat and environmental monitoring, structural monitoring (e.g.: bridges), monitoring of contaminants, smart roads, intruder detection, battlefield surveillance. It is complementary to classical surveillance with a few large/costly sensors hierarchically organized. The network of numerous sensors and communication nodes (for instance: peer-to-peer networks) may have time-varying link topology due to both natural and artificial interferences, e.m. propagation masked by the terrain surface, meteorological conditions, dust and smoke which might be present at times in the environment. These networks should be designed to be resilient to ECM, cyber attacks and should be able to manage increasing and highly variable flow of data. Because the connections between pairs of nodes are not directly related to their physical distance but, rather, to the number of hops in the network, the underlying geometry is not a Euclidean flat geometry. This observation brings new frontiers in the detection and estimation/filtering theories on network topologies [18].

Smartphones are rapidly becoming the computer platform of choice in developed and developing nations. We carry smartphones with us nearly everywhere. Smartphones are allowing us to communicate, buy, sell, connect, and do miraculous things. This mobile technology, coupled with new sensing and software, can enable us to go beyond finding friends, chatting with colleagues, locating hip bars, and buying music. In today's pandemic time, they are playing a role in tracing the virus diffusion [18].

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[1] Italics added by the authors of this paper.

Indeed the view of Professor Chernyak, echoing the title of [52], is entirely appropriate to the present day.

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