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Expert System CFAR: Algorithm Development, Experimental Demonstration, and Transition to Airborne Radar Systems

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INTRODUCTION

The genesis of the Expert System Constant False Alarm Rate (CFAR) processing arose in 1984 from insight gained during earlier experiments performed at the Air Force Research Laboratory's Rome Research Site, then known as Rome Air Development Center (RADC) (Figure 1). Measured data analysis from the low altitude detection (LAD) experiments conducted in RADC's Surveillance Laboratory was instrumental in gaining insight into detecting weak signals (airborne target returns) embedded in strong nonhomogeneous clutter. This challenging problem, investigated by Signal Processing Chief, Mr. Clarence Silfer in the late 1970s, was studied to improve cruise missile detection by unattended short-range ground-based radars. The LAD experiments were performed in support of the Enhanced Defense Early Warning (EDEW) project [1]. Dr. Russell Brown and Mr. David Mokry conducted measurements in the summer of 1981, and Mr. Paul van Etten performed analysis. The first author assisted in these early endeavors, focusing on data analysis.

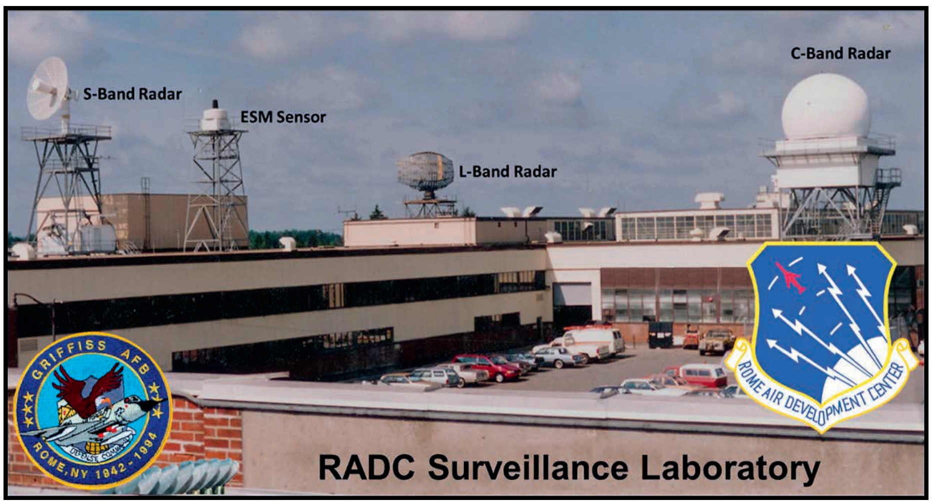

Figure 1.
US Air Force ground-based radar test bed in Rome, NY.

A track-while-scan (TWS) instrumentation radar was used for data collection. This coherent radar (waveform generation, timing, and control implemented via programmable emitter coupled logic) operated with up to 60 MHz of signal bandwidth at L-Band, employing a 150 KW traveling wave tube for the final stage of high-power amplification on transmit and superheterodyne down conversion on receive. This type of radio receiver uses stages of frequency mixing, amplification, and filtering to convert a microwave signal of interest to a fixed intermediate frequency (IF). The resulting IF signal, a fully coherent yet frequency-shifted replica of the received microwave signal, is more conveniently down-converted to baseband, digitized, processed, and/or recorded.

This L-Band instrumentation radar, integrated in 1981 with an AMPEX Corp HBR-3000 digital data recorder and interfaced via a buffer memory to a Floating Point Systems AP-120B array processor, was under the control of a Hewlett-Packard HP 1000 L-Series computer. This made data collection, quick-look calibration, and in-depth postmission signal and data processing possible. An embedded four-channel sidelobe canceller was instrumental in mitigating in-band sidelobe interference in the LAD radar data collection experiments.

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The goal of this measurements-driven and phenomena-oriented research was clear and simple—to explore the impact of very low threshold detection processing on track formation in a fully coherent TWS radar with an embedded four-channel sidelobe canceller. The test targets of greatest interest were small, slow moving aircraft flying 100 m above ground level. All experiments were conducted in close proximity (40 km) to the radar test bed. Research focused on exploiting coherent clutter maps, autoregressive superresolution spectral estimators, and Kalman filter-based noisy area TWS processing. Postmission analysis of data demonstrated that slow moving targets often "broke track" due to residual interference in one or more Doppler filters. This was caused by strong backscatter signals from natural terrain and close-in manmade structures in addition to electromagnetic interference. The early conjecture was that internal clutter motion and scanning modulation would also contribute to degraded track performance, but it was later determined that these effects were negligibly small by comparison.

The weak returns from low, slow test aircraft most interested the analysis team. We initially implemented an adaptive Doppler processor followed by a three-dimensional cell-averaging constant false alarm rate (CA-CFAR) detector, with a crude form of extreme value excision. This "modified" multidimensional CA-CFAR, a detector that spanned range, angle, and Doppler, was permanently incorporated into the L-Band radar signal and data processing chain (in software on the AP-120B array processor). The team decided that a symmetric training data window was adequate only for initial analysis, and that detector performance would indicate the direction for future CFAR research. Analysis employing multiple detectors immediately followed. Both the greatest-of (GO) and trimmed mean (TM) CFAR were investigated. Topographical maps and a coherent clutter map (using only several Doppler filters) were used as information sources (an early, albeit self-generated knowledge source) for suppressing outliers and to compute clutter-plus-noise power estimates in regions of heterogeneous terrain. It was soon verified that the effects of outliers were greatly reduced using multiscan training data in range, angle, and Doppler. The track processor was also utilized to excise persistent returns from "stationary movers" spatially localized in the training data. Furthermore, asymmetric training data windows were employed due to the close proximity (of the slow movers) to the zero Doppler filter and the effects of numerous dominant structures surrounding the radar test bed.

In late 1981, the LAD experiments proved successful and Mr. Silfer transitioned results to the sponsor. Gains in wide area surveillance radar performance would be enabled by improvements in track processing, with appropriate changes to Doppler filtering, sidelobe cancellation, and especially false alarm control. This research concluded with little fanfare, as the topic of ground-based wide area surveillance radar was no longer of great interest to the basic research community. However, this experience influenced the careers of many radar engineers at RADC, as weak target detection became the focus of signal processing experiments in the Surveillance Laboratory for the next three decades.

EXPERT SYSTEM CFAR CONCEPT DEVELOPMENT

In 1984, as technical leader of the seedling in-house Air Defense Initiative (ADI) at RADC, Dr. Richard Schneible requested support from the Surveillance Laboratory staff to develop advanced radar technology in order to improve weak signal detection in wide area surveillance radars via advanced airborne moving target indication (AMTI), Doppler processing, and track formation. This futuristic ADI radar was to be a "concept car" [1] designed to foster discussion and provide a baseline for developing a post-AWACS (airborne warning and control system) radar capability. Similar to the EDEW project, the mission was to develop a wide area surveillance capability for detecting and tracking the modern air-breathing threat under all weather conditions, albeit now from an airborne sensor platform.

At RADC, we had examined the link budget for the airborne radar in operation onboard AWACS. Significant performance gains were theoretically possible through signal and data processing. However, large gains were not practically achievable through

[1] Concept cars were popular in the automotive industry during the mid-20th century as a means of illustrating planned or potential futuristic body styles.

Figure 2.
Increased power-aperture product is not always feasible.

increased radar aperture or dramatically higher average transmit power (light-heartedly described with the graphic in Figure 2). The simple goal was to look for immediate gains in filtering, false alarm control, and track processing. At that point, management and leadership were open to all suggestions. Mr. Fred Demma, Chief of Surveillance Technology at RADC, heavily promoted a philosophy of “MASS for MIPS” in which we emphasized algorithm development and computing solutions over power-aperture, all while remaining cognizant of the limitations due to the thermal noise floor. An investigation into target correlation on extended coherent dwell ensued [2].

Multiple researchers responded to Dr. Schneible's call for technology solutions to this challenging AMTI problem, including members of the aforementioned LAD research team. Dr. Brown focused on improving the linear dynamic range of the radar receiver and improving the balance of the in-phase and quadrature baseband signals. This proved extremely beneficial for realizing enhanced coherent processing. This research motivated Dr. Brown to develop novel IF sampling techniques using out-of-band noise injection that aided in developing the Expert System CFAR. Mr. van Etten studied the application of modern spectral estimators to ADI, specifically focusing on autoregressive techniques to address the problem of weak signal suppression [3]. Mr. Thomas Maggio, also from RADC, was instrumental in applying a coherent form of the noisy area tracker, a noncoherent track technique put into production using analog phosphor storage in the 1960s. Mr. Maggio investigated techniques for analyzing postdetection declarations, separating false alarms from desired signals via “real-time” statistical methods. At that same time, Mr. Robert Ogrodnik from RADC sponsored Mr. Alan Corbeil, Dr. John DiDomizio, and Mr. Lee Moyer, all from the Technology Service Corporation, to investigate track before detect (TBD) [4], a knowledge-aided, fully coherent, and much improved form of the aforementioned noisy area tracker.

Dr. Schneible assigned the task of trade space analysis between and among these and other signal and data processing techniques to the first author. Initial results indicated that an improved CFAR detector would yield a cost effective and immediate benefit to airborne wide area surveillance radar, as the adaptive threshold multiplier could be systematically reduced, weaker returns detected, and false alarms precluded with improved exploitation of clutter statistics. An Expert System CFAR would increase computational complexity only modestly, and computing was a cost driver in the mid-1980s. We pursued concept development, systems engineering integration, and theoretical (statistical) analysis of the emerging Expert System CFAR in addition to research in space-time adaptive processing (STAP) for clutter rejection in airborne radar [5]. STAP is a form of multidimensional spatial-temporal filtering that potentially improves detection performance in airborne early warning and ground moving target indication (GMTI) radar.

Fortuitously, Dr. Northup Fowler, a software expert and senior research scientist at RADC, was independently pursuing intelligence, surveillance, and reconnaissance applications of innovative techniques in advanced computing. Dr. Fowler pursued, among other software technology, a form of programming that emulates the knowledge and analytic skills of a human expert. Furthermore, basic and early applied research funds from the office of the Chief Scientist became available to scientists and engineers conducting research in this area, especially in speech and radar signal processing, in order to apply expert reasoning software to enhance the real-world performance of mathematical algorithms. Our research in Expert System CFAR detection processing received additional support from the office of the Chief Scientist.

The research of Dr. Hermann Rohling [6] further motivated the first author to pursue a more rigorous systems-oriented design of the Expert System CFAR detector. We took several months to study the problem and propose a detector with the potential for performance improvements but with limited demands for high-end computing. In that era, real-time embedded parallel processing was experimental in nature, extremely costly, and oriented towards space applications [7]. We proposed a technology solution that required very little advanced computing hardware. This solution, which has since impacted several fielded systems, was designed for simplicity of implementation. We proposed to run several different (albeit well characterized) CFAR detector algorithms in parallel, and to fuse these detector results using conventional algorithms. The menu of standard CFAR detector algorithms included cell averaging (CA), GO, TM, ordered statistic (OS), and smallest of (SO). Additionally, several advanced CFAR detector algorithms developed by Mr. James Sawyers from the Hughes Aircraft Company (now Raytheon) were included. We leveraged conventional fusion and track processing algorithm technology developed independently by colleagues Dr. Pramod Varshney from Syracuse University and Dr. Yaakov Bar-Shalom from the University of Connecticut. These techniques were used to integrate the various CFAR detector decisions and to produce a global declaration of target present or target absent.

We fully understood that fusion algorithms were all developed under the assumption that each data input to the decision processor was independent of all others, and this was clearly not true in Expert System CFAR. In the problem under analysis, identical data is processed using various CFAR detectors, and a global decision made using the aforementioned fusion rules. Still, we explored this algorithmic approach experimentally, and developed the technology more fully as performance proved worthy. Initial demonstrations in the Surveillance Laboratory at RADC were astonishing! In clutter and electromagnetic interference limited environments, the earliest Expert System CFAR outperformed all other CFAR detectors. At that same time, Dr. Vincent Vannicola from RADC began to explore the theory of predetection fusion [8] and to demonstrate performance using data from the L-, S-, and C-Band radars in the Surveillance Laboratory. Dr. Hong Wang from Syracuse University and Dr. Brown developed adaptive multiband polarization [9] processing technology in addition to polarization STAP. We leveraged these technology investigations to benefit the development of Expert System CFAR.

A formal effort to quantify performance, to package, and to transition the Expert System CFAR more widely began in 1990. In system design and analysis, it became obvious that each detector embedded within the Expert System CFAR was optimum only under very restrictive conditions, and, as such, would perform below optimum when those conditions were not met, which was most of the time. Furthermore, each CFAR detector could perform well below optimum when severely mismatched to real-world operating conditions. For example, a CA-CFAR detector operating close to a land-sea interface could exhibit unacceptably high losses (order of magnitude) in detection performance. Alternatively, in a multi-target environment, a highly selective (very few training samples) TM-CFAR could dramatically out-perform all other CFAR detectors, but perform poorly in homogeneous clutter or beyond the clutter line-of-sight.

The accurate estimation of the underlying spatial-temporal clutter probability density function (PDF) was an intense area of research in the 1980s. Contributions by Drs. Donald Weiner and Aydin Ozturk of Syracuse University dramatically affected the Expert System CFAR. Dr. Ozturk's research produced a mathematical technique now known as Ozturk's algorithm that focuses on the use of very small data sets (i.e., minimal sample support) to estimate PDFs accurately, including an accurate estimate of statistical tails [10].

That first Expert System CFAR was conceptually very simple, with several different OS-CFAR and TM-CFAR detectors (with any individual TM-CFAR detector using very few training data–5 to 10 at most) all running in parallel, each processing the same radar data, with CA-CFAR as a baseline for comparison. Training data sets of various sizes were employed, and analyzed via a statistical bootstrap technique (repetitive random sampling with replacement) for estimating the mean clutter-plus-noise power in order to provide an improved estimate of the interference in each cell under test. Initially, fusion was accomplished via majority rule polling of the various detector outputs. Other, more sophisticated fusion rules, as well as Ozturk's algorithm, were later applied.

Many signal-processing experts told us not to pursue this line of reasoning because the data being processed and fused were 100% dependent, and as such, results would be disappointing. However, their analysis proved erroneous due to one simple reason. Any one CFAR detector algorithm is matched to the environment only under very restrictive conditions, and these conditions are rarely met. We were fusing the results of several suboptimum, albeit real-world detectors, and as such, fully expected to improve overall performance.

TECHNOLOGY DEVELOPMENT AND DEMONSTRATION

Rome Laboratory supplanted RADC upon its establishment in the early 1990s. About this same time, the second development stage of this technology began. The second author, chief architect and developer of the fielded product we now call Expert System CFAR, led this effort [11]. His team included a number of investigators, including Dr. Paul Antonik and Dr. Gerard Capraro, researchers investigating multiple fields: real-time processing, parametric analysis, modeling and simulation, and software engineering, respectively. Dr. Varshney and Dr. Weiner from Syracuse University also formally joined the research team, as did Dr. Murali Rangaswamy [12]. In this effort, we developed an extensive rule-based approach to enhance performance of the aforementioned fusion processor. In the final product, only four CFAR algorithms were selected. They were CA, GO, OS, and TM-CFAR; the first three detectors are all examples of TM- CFAR. With no trimming, we obtain CA-CFAR. With maximum trimming (all but one sample), we obtain OS-CFAR. In addition, with range averaging before trimming (of the weakest training data), we obtain GO-CFAR. Figure 3 depicts an early flow diagram of the prototype Expert System CFAR processor developed using FORTRAN and Gensym's G2.[2]

Mathematically SO-CFAR employs as training data the alternative set resulting from the logical “and” union of CA-CFAR and GO-CFAR training data. Through these and similar mathematical and philosophical constructs, dozens of CFAR algorithms and hundreds of rules were reduced to a few detector algorithms, control parameter sets, and heuristic rules, all without significant performance degradation.

With surface maps (surface elevation data, surface cover data [e.g. trees, grass], and cultural data [e.g. dense urban]), and only 11 rules and four CFAR detectors, a robust Expert System CFAR was developed, and performance demonstrated using measured AWACS data. This data, containing modern air-breathing targets embedded in clutter, was analyzed using a variety of competing CFAR approaches. Expert System CFAR was demonstrated to be genuinely superior [13]. Performance margins of several dB are reported in the literature. See the references for more details [14], [15]. In clutter-free environments (e.g. Gaussian white noise), Expert System CFAR performs as well as CA-CFAR due to the development of a robust rule-base.

TECHNOLOGY TRANSITION

The third and final stage of this effort was transition. This technology was successfully transitioned to the user community in the 1990s. Two classes of surveillance radar were considered as transition opportunities: initially, the E-3 AWACS airborne early warning radar followed by the E-8 JSTARS air-to-ground imaging and target tracking radar.

The CFAR processor used by AWACS was implemented as a baseline for comparison to Expert System CFAR. Radar data collected by the E-3 AWACS was analyzed using Expert System CFAR processing and compared with the AWACS baseline (Figure 4). On a per coherent processing interval (CPI) basis, Expert System CFAR demonstrated an order-of-magnitude reduction in false alarms and improved detection in difficult and cluttered environments. This represented a sensitivity improvement typically asso-

[2] See *www.gensym.com/products*.

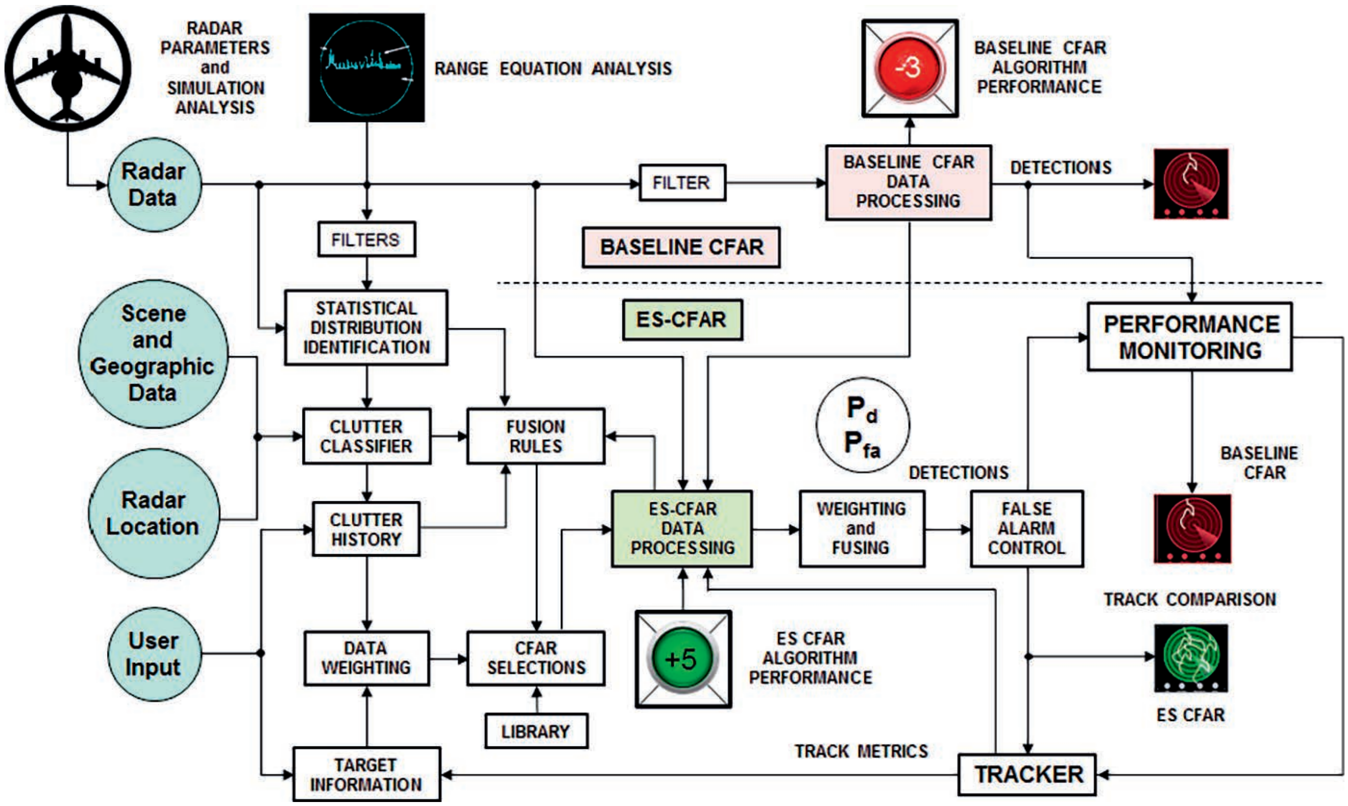

Figure 3.
Prototype Expert System CFAR detection processor.

ciated with significant increases in power-aperture product. It was instead accomplished with advanced signal processing consisting of characterization of the underlying interference, knowledge of the conditions where each CFAR algorithm performs optimally, and smart but simple rules to guide in their selection. This signal processing technique, simple in nature, produced an average performance increase of approximately 7 dB!

By the mid-1990s, the Air Force had reorganized its four laboratories into a consolidated organization known as the Air Force Research Laboratory (AFRL), which remains in existence today. The research continued within the Sensors Directorate of AFRL into the early 2000s when Dr. Joseph Guerci, a respected colleague, initiated technology development at Defense Advanced Research Projects Agency (DARPA) under a program known as KASSPER (Knowledge-Aided Sensor Signal Processing and Expert Reasoning). This program sought to maximize the payoff from heuristic signal and data processing, and especially to formalize the architectures needed to field this important technology widely and affordably. Dr. Guerci, along with the authors and their colleagues, integrated this technology with waveform diversity, track processing, and parameter estimation. The second author elected to manage the KASSPER program and to focus on two key areas of intended accomplishment. First, he sought to develop a test bed in order to integrate various knowledge-

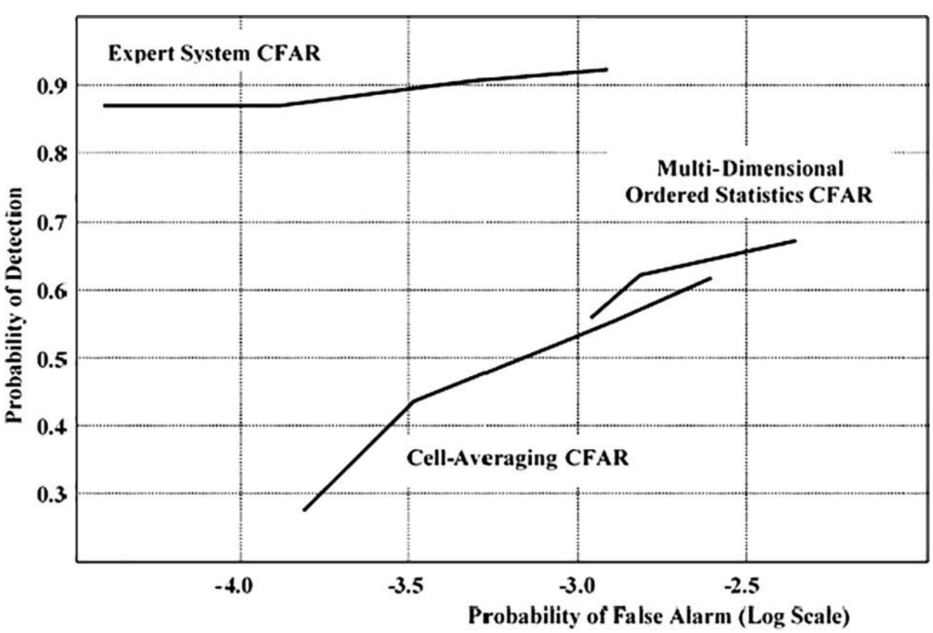

Figure 4.
Expert System CFAR results using measured E-3 AWACS radar data.

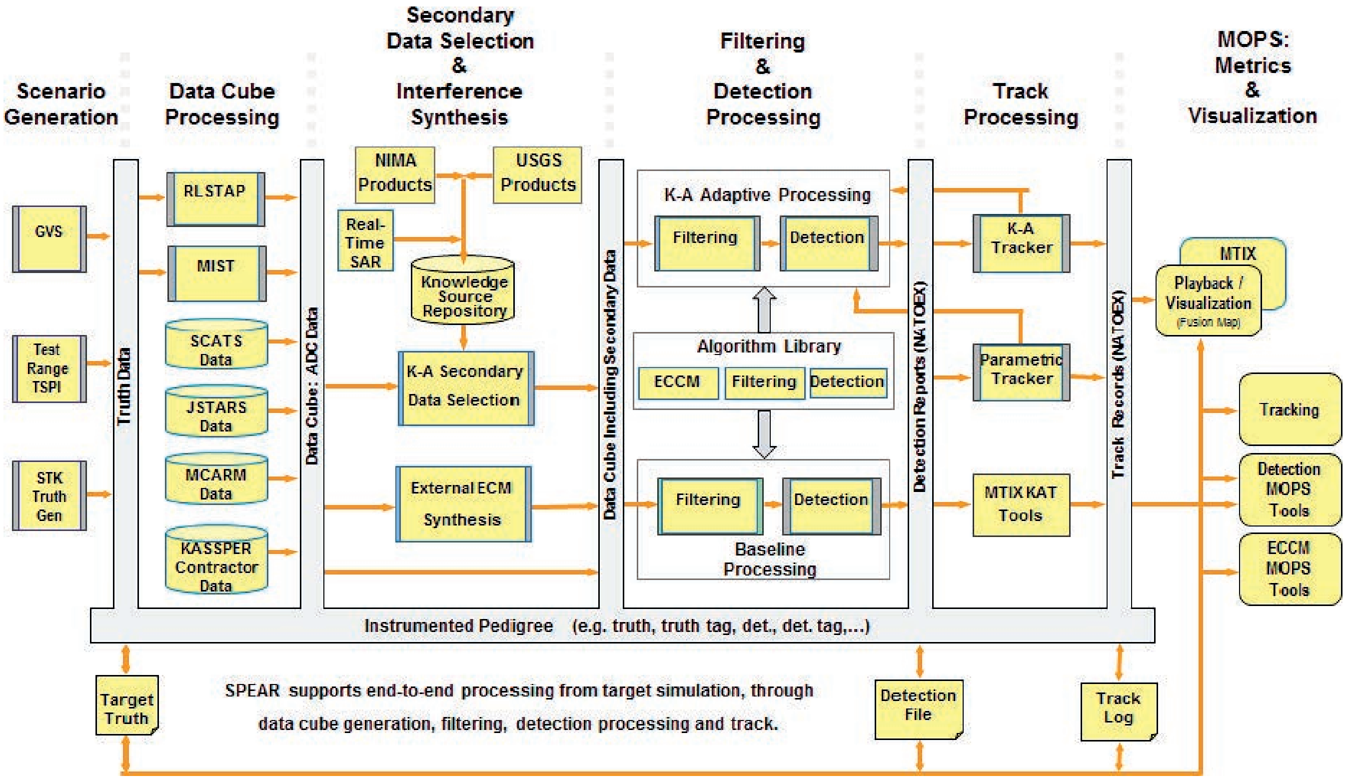

Figure 5.
AFRL Sensors Directorate SPEAR test bed.

aided (KA) algorithms for filtering, detection, and track processing; databases and "knowledge sources" to aid in the understanding of the environment; sources of measured and simulated datasets to be used in research, assessment, and demonstration; metrics tools for assessing performance; and visualization of results [16]. Second, building on the first key area, he sought to demonstrate performance enhancements to the E-8 JSTARS using KA techniques, analogous to the E-3 AWACS results demonstrated a decade earlier.

The SPEAR test bed (Signal Processing Evaluation, Analysis, and Research) was built and is illustrated in Figure 5 [17]. The humble and simple beginnings of the Expert System CFAR processor in 1984 gave rise to an entirely new way of approaching sensor signal and data processing. As shown in the figure, numerous innovations and over two decades of development were brought together in this test bed—filtering, especially STAP, detection, and track algorithms; modeling and simulation (M&S) tools; data sets (simulated and measured); knowledge sources; and tools for measures of performance (MOPS). The contributions of Mr. Todd Cushman and Mr. Mark Novak from AFRL and Mr. Walter Szczepanski, Mr. Robert Bozek, and Mr. Jeff Tyler of Black River Systems Company were critical in implementing the SPEAR test bed. An important aspect of the aforementioned MOPS tool is the linkage it created between signal and data processing enhancements, typically reported in terms such as test statistics, PDF, SINR, SINR loss, or Pd, and Pfa, and corresponding tracking and exploitation metrics more commonly employed and understood by Air Force users and operators. The ability to "translate" and articulate signal processing enhancements in terms more readily interpreted by operators was a major factor in transitioning Expert System CFAR and subsequent KA signal and data processing technology to the Air Force and the rest of the user community. Concurrently, Mr. Jon Jones of AFRL's Information Directorate was very influential in shaping the MOPS tool, elevating track processing, and especially raising data exploitation technology to a much higher level of sophistication and acceptance by the user community.

The SPEAR test bed enabled a series of performance assessments to be conducted, including Expert System CFAR for JSTARS, as well as various configurations of KA processing for Global Hawk and other candidate transition platforms. Performance improvements using Expert System CFAR were indeed demonstrated for JSTARS using real-world measured data in heterogeneous clutter environments (mountains/desert) with several slowly moving, closely spaced ground targets (analysis and demonstration of results presented to and lauded by the 2002 US Air

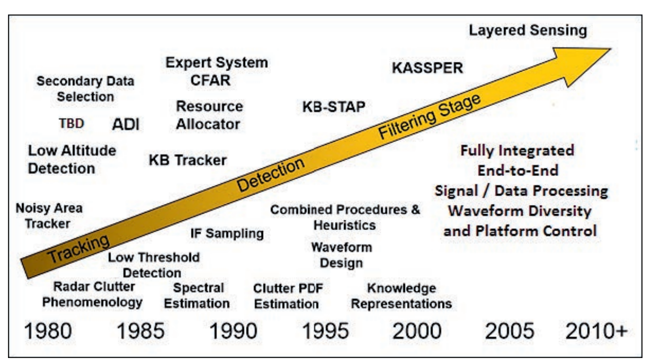

Figure 6.
Expert System CFAR and technology development timeline.

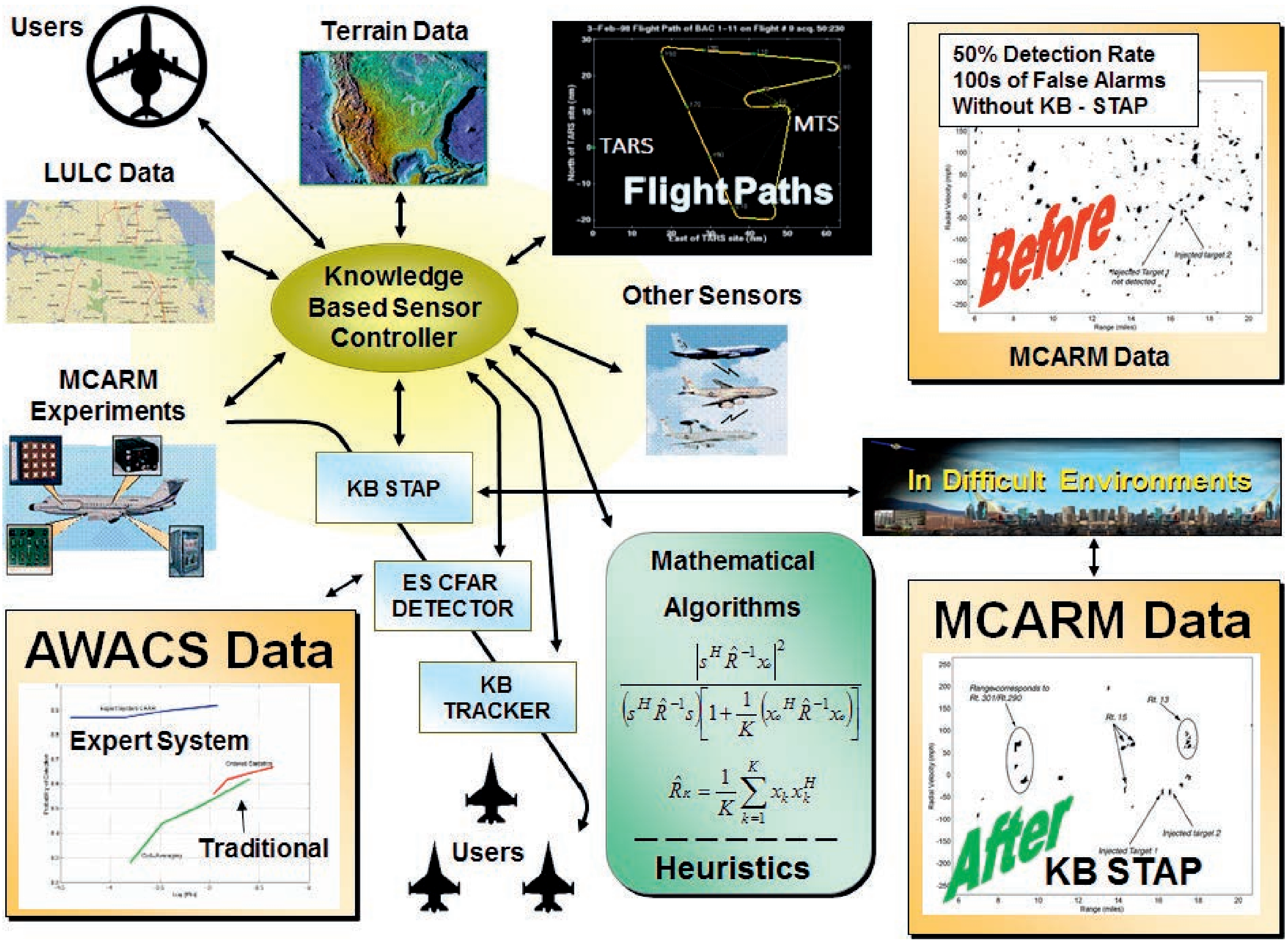

Figure 7.
Expert System CFAR led to knowledge-based STAP [20].

Force Scientific Advisory Board). Subsequent embracing and maturation by DARPA resulted in transition of Expert System CFAR to JSTARS in the Block 40 tracker upgrade.

FUTURE RESEARCH DIRECTIONS

The research and development of Expert System CFAR began over 30 years ago and built from a solid foundation across many disciplines and into many research domains. This can be appreciated in Figure 6. It has shaped a way of thinking about signal and data processing that has changed the nature of US Department of Defense (DOD) radar technology for adaptive filtering, detection processing, as well as track formation, target identification, and engagement [18].

As the Air Force pursues a vision for layered sensing, Expert System CFAR and subsequent developments in knowledge-based STAP and KA processing provided a compelling motivation to extend the paradigm further into waveform agile, multiplatform, multisensor, and multidomain instantiations of layered sensing in order to meet future warfighting needs in complex environments. Analysis of multichannel airborne radar data demonstrates the impact of Expert Systems and knowledge-based processing on layered sensing. In the upper and lower right of Figure 7, the impact of heuristic processing on STAP is demonstrated via “Before” and “After” results. In this graphic, knowledge-based STAP includes nonhomogeneity detection [19] (analogous to excising outliers in TM-CFAR), the application of corrected (measured) steering vectors, the exploitation of prior knowledge sources and data from previous flights in heuristic and algorithmic radar signal and data processing for target detection, and interference rejection in airborne radar. ◆

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REFERENCES

[1] Smith, J., and Byrd, D. Forty years of research and development at Griffiss Air Force Base. Rome Laboratory, Griffiss AFB, NY, Tech. Rep. RL-TR-92-25, AD-A250 435, July 1992.

[2] Weiner, D., and Song, J. Improvements in radar detection under scan to scan processing and scan rate reduction. Rome Laboratory, Griffiss AFB, NY, Tech. Rep. RL-TR-91-80, AD-A247-350, June 1991.

[3] Silfer, C. et al. *Proceedings of the RADC Spectrum Estimation Workshop*, Rome Air Development Center, Griffiss AFB, NY, Oct. 1979.

[4] DiDomizio, J., et al. Track-before-detect development and demonstration program. Rome Air Development Center, Griffiss AFB, NY, Int. Tech. Rep., Mar. 1985.

[5] Wicks, M. et al. Clutter considerations in modern radar systems. Rome Air Development Center, Griffiss AFB, NY, Tech. Rep. RADC-TR 88-252, Vol. 2, Oct. 1988.

[6] Rohling, H. Radar CFAR thresholding in clutter and multiple target situations. *IEEE Transactions on Aerospace and Electronic Systems*, Vol. AES-19, 4 (July 1983), 608–621.

[7] Dechant, D. The advanced onboard signal processor. *Journal of VLSI Signal Processing Systems*, Vol. 2, 2 (Oct 1990).

[8] Willet, P. et al. The case for like-sensor pre-detection fusion. *IEEE Transactions on Aerospace and Electronic Systems*, Vol. AES-30, 4 (July 1994).

[9] Brown, R., and Wang, H. Adaptive multiband polarization processing for surveillance radar. In *1991 IEEE International Conference on Systems Engineering*, Dayton, OH, Aug. 1991.

[10] Weiner, M. (Ed.). *Adaptive Antennas and Receivers*. London: CRC Press, 2005.

[11] An expert system constant false alarm rate (ES-CFAR) processor, U.S. Patent 5,499,030, Apr. 1996.

[12] Antonik, P. et al. ES-CFAR reports intelligent use of CFAR algorithms. Rome Laboratory, Griffiss AFB, NY, Tech. Rep. RL-TR-93-75, AD-A267-755, June 1991.

[13] Baldygo, W. et al., Artificial intelligence applications to constant false alarm rate (CFAR) processing. In *Record of the 1993 IEEE National Radar Conference*, Lynnfield, MA, Apr. 1993.

[14] Wicks, M. et al. Space-time adaptive processing: A knowledge-based perspective for airborne radar. *IEEE Signal Processing Magazine, Special Issue on Knowledge-Based Systems*, Vol. 23, 1 (Jan. 2006), 18–29.

[15] Capraro, G. et al. Knowledge-based radar signal and data processing. *IEEE Signal Processing Magazine, Special Issue on Knowledge-Based Systems*, Vol. 23, 1 (Jan. 2006), 18–29.

[16] Guerci, J. et al. The KASSPER eye-watering scenario. In *Proceedings of the 2004 DARPA/AFRL KASSPER Workshop*, Clearwater Beach, FL, Apr. 2004.

[17] Baldygo, W., et al. AFRL KASSPER algorithm test bed. In *Proceedings of the 2002 DARPA/AFRL KASSPER Workshop*, Washington, D.C., Apr. 2002.

[18] Baldygo, W. et al. Sensors technology and advanced signal processing concepts for layered warfare/layered sensing. Air Force Research Laboratory, Wright Patterson AFB, OH, Tech. Rep. AFRL-RY-RS-TR-2010-100, AD-A519-954, Apr. 2010.

[19] Wicks, M. et al. An efficient architecture for non-homogeneity detection in space-time adaptive processing airborne early warning radar. In *Proceedings of the 1997 International Radar Conference*, Edinburgh, United Kingdom, Oct. 1997.

[20] Wicks, M. Knowledge-based control for space time adaptive processing. Paris, France, Tech. Rep. RTO-EN-SET-063, Sept. 2006.