HABILITATION THESIS

Advanced Signal Processing Techniques in the Field of Electronic Warfare

Scientific Domain:
Electronic Engineering and Telecommunications

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This habilitation thesis is dedicated to my family: Claudia and Alexandru
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Chapter 1

Abstract

1.1 Abstract

The present habilitation thesis is a cumulative synthesis of my relevant professional and research results achieved in the period 2004-2015, following the public presentation of my doctoral thesis in 2003.

In this period, my research activity covered four important research areas: Automatic target recognition (ATR) systems, High-resolution radar (HRR) signal processing, Hybrid artificial intelligence (AI) paradigms and Electronic warfare (EW), respectively. These are the core domains of my professional training and education.

The present habilitation thesis is structured into three parts. The first part overviews concisely my teaching and research activities. The second part presents the most important achievements related to the four major research fields mentioned above, each interesting research direction being fully-described in a dedicated section. The third part draws the future objectives and directions of scientific research in the fields presented before. Also, two comprehensive annexes present the general references and the list of my scientific publications.

The main core of this habilitation thesis is geared on my scientific research directions and achievements which are synthetically described hereinafter.

In ATR systems research field, my work was mainly focused on identifying and testing more efficient and performing classification/PR chains for different spectral input information flows (belonging to video, thermal and HRR imageries). Consequently, there were investigated some improved techniques of feature extraction (i.e., a new set of invariants related to Flusser moments family) and selection (i.e., a generalized (neural) version of the standard Sammon mapping algorithm) for a pattern of interest. To increase the recognition accuracy of an ATR system, an advanced decision fusion technique based on Sugeno’s fuzzy integral was proposed. Furthermore, another approach to assure the highest classification rate was centered on the development of new customized PR chains. Finally, there were also discussed some improved design solutions in the field of automatic license plate and speech recognition, respectively.

My research activity in the ATR systems area was materialized in a national grant conducted by me as a project manager and five national projects, all following competitions, in which I was involved as a research team member. The experience accumulated working for these projects was put to use both to improve the scientific level of the courses I taught and to upgrade some of the facilities in the department’s laboratories (e.g., a modern anechoic chamber into audio spectrum, some dedicated PR/data fusion processing tools etc.). Moreover, I published more than 25 papers on this topic, among which 15 (10 as first author) in various prestigious ISI ranked journals and conferences with ISI CPCI proceedings. In addition, I co-authored a book in the field of EM image processing.

In the field of HRR signal processing, my work was mainly focused on designing new robust algorithms (concerning the level of the sidelobes) for the synthesis of NLFM signals and on studying some advanced superresolution methods in order to improve the quality of the available HRR imagery database. Consequently, the proposed NLFM synthesis techniques were based on both temporal predistortioning of LFM signals and stationary phase concept. In point of novelty, the proposed approach provides an effective modality to optimize (using the
sidelobe reduction criterion) the specific parameters of the investigated NLFM synthesis methods. Moreover, by applying such advanced algorithms alongside with minute simulations, a significant sidelobe suppression (more than -40 dB, on average) was obtained. Finally, my research activity was also focused on both the theoretical and experimental investigation of some superresolution techniques used to generate the target HRRPs and the design of suitable reconstruction algorithms of the target radar images for different PR tasks, respectively.

It is worth noticing that the main results achieved in the HRR signal processing area were supported by two national projects following competition in which I was involved as a research team member. In addition, I published more than 10 papers, among which 7 (5 as first author) in various well-known ISI ranked journals and conferences with ISI CPCI proceedings.

The fusion between the standard connexionist models and some relatively recent mathematical theories had as effect an explosive theoretical and experimental development of new powerful hybrid AI (also known as neuro-fuzzy-genetic) architectures. In this still promising research area, my activity was mainly targeted at investigating, theoretically and experimentally, some hybrid AI paradigms, focusing directly on both GANN systems theory and their hardware implementations. Consequently, there were proposed two improved algorithms used to ensure a full-training genetic procedure for both RBF (i.e., a GARBF system) and MLP (i.e., a GAMLp system) networks. Within this framework it was also carried out a comparative study between the current approaches based on FPGA technology and some of the standard neurohardware solutions.

The relevant results of my research in the hybrid AI paradigms domain were the outcome of my work as a research team member in four national projects following competition. In this context, I published more than 15 papers, among which 10 (8 as first author) in various prestigious ISI ranked journals and conferences with ISI CPCI proceedings. Moreover, it is worth mentioning that I was the single author of three books introducing important approaches in the field of hybrid AI models and the co-author of a book in the GANN systems theory domain.

Generally, my research activity in the EW domain can be divided into two important directions, i.e., the publishing activity and the actual research activity, respectively. I think that it is very important to start by mentioning that Romanian literature faces a major lack of current information in the technical field of EW. Taking that into account, my publishing activity is significant coming as a result of many years of scientific documentation in this area. Consequently, it is worth mentioning that I was the single author of two reference books in this field (very importantly, a unique endeavor in Romanian EW literature, so far). In addition, I published two more books as single author and co-authored another book, all extremely useful for understanding some theoretical and practical aspects of EW.

The actual research activity in the EW field was carried out as a project manager of three projects of the Defense Ministry’s research program or as a research team member in two projects of the same program. It is also important to mention that I was involved in more than twelve national research projects following competition, acting as a research team member.

An additional direction of interest in the EW field appeared from the necessity to understand the complex connections between EW and other modern concepts of the current military battlefield (e.g., the NCW concept). In this area, I published more than 25 papers, among which 15 (10 as first author) in some prestigious ISI ranked journals and conferences with ISI CPCI proceedings.

The consistent research experience and expertise achieved in the EW domain allowed me to participate in specific standardization and military acquisition activities. Consequently, I was involved as a member of the working team (2004-2008), either in the development or the acceptance of four MIL/STANAG standards. In addition, in 2010, I participated as a technical expert, in an acquisition group of some dedicated military products for the aviation EW area.
1.2 Rezumat

În cadrul acestei teze de abilitare sunt prezentate cele mai importante rezultate obținute în perioada 2004-2015, atât în plan profesional, cât și în activitatea de cercetare științifică. Această perioadă este cea a urmat anului 2003, an în care am susținut teza de doctorat.

În perioada mai sus menționată, activitatea mea de cercetare a cuprins patru direcții majore de cercetare științifică: Sisteme de recunoaștere automată a țintelor (ATR), Procesarea semnalelor radar de înaltă rezoluție (HRR), Paradigme hibride ale inteligenței artificiale (AI) și respectiv, Războiul electronic (EW). Practic, aceste patru domenii de interes au reprezentat și baza întregii mele pregătiri profesionale.

Teza de abilitare este structurată în trei părți distincte. Astfel, prima parte este un rezumat sintetic al activității mele didactice și de cercetare științifică. În partea a doua sunt prezentate cele mai importante realizări în domeniile de interes amintite anterior, fiecare direcție de interes fiind descrisă în detaliu, într-o secțiune separată. Partea a treia a tezei de abilitare trasează direcțiile de dezvoltare și obiectivele de lucru în domeniile de cercetare prezentate anterior. De asemenea, această lucrare conține și două anexe comprehensive care prezintă bibliografia generală și lista publicațiilor mele științifice.

În domeniul sistemelor ATR, activitatea mea de cercetare științifică a fost focalizată în principal, pe identificarea și testarea unor lanțuri de clasificare eficiente din perspectiva unor fluxuri informaționale de intrare diferite (aparținând imageriilor de tip video, termal și HRR). Prin urmare, au fost investigate unele tehnici îmbunătățite de extragere (un nou set de invarianți aparținând familiei momentelor Flusser) și respectiv, selecție (o versiune (neuronală) generalizată a algoritmului standard de proiecție Sammon) a caracteristicilor unei forme de interes. Pentru creșterea acurateții de recunoaștere a unui sistem ATR, a fost propusă o tehnică avansată de fuziune decizională bazată pe integrala fuzzy Sugeno. Suplimentar, tot în contextul creșterii ratei de clasificare, o altă direcție vizată a fost avansarea criterionului cost-effort, a algoritmului standard de proiecție Sammon) iar în ultimul rând, am fost co-autor la o carte în domeniul procesării semnalelor HRR.

Activitatea mea de cercetare științifică în domeniul sistemelor ATR s-a concretizat într-un proiect național pe care l-am condus în calitate de director de proiect și respectiv, cinci proiecte naționale, toate prin competiție, în care am fost implicat ca și membru în echipa de lucru. Experiența acumulată prin aceste proiecte de cercetare științifică a fost utilizată atât în îmbunătățirea cursurilor predate, cât și în dezvoltarea unor facilități moderne în laboratoarele departamentului (spre exemplu, o cameră anecoidă în spectrul audio, unele instrumente de procesare dedicate în domeniul recunoașterii formelor/fuziunii de date etc.). De asemenea, am publicat peste 25 de articole în acest sens, dintre care 15 (10 ca autor principal) în diferite reviste indexate ISI sau proceedings-urile unor conferințe ISI CPCI. Nu în ultimul rând, am fost co-autor la o carte din domeniul procesării imaginilor electromagnetice.

În domeniul procesării semnalelor HRR, activitatea mea de cercetare științifică a fost focalizată în principal, pe proiectarea unor algoritmi robusti (ca și nivelul al lobilor secundari) de sinteză a semnalelor de tip NLFM și respectiv, pe studiul unor metode avansate de înaltă rezoluție, totul în ideea creșterii calității bazei de date HRR avută la dispoziție. În consecință, tehnici de sinteză propuse au avut un impact direct în elaborarea unor sisteme de recunoaștere eficiente și eficace în domeniul HRR. Acest lucru a contribuit semnificativ la îmbunătățirea performanțelor sistemelor ATR, atât din punct de vedere prin creșterea acurateții de recunoaștere, cât și prin creșterea preciziei și specificității clasificării țintelor.
activitatea mea de cercetare științifică a presupus și investigarea atât la nivel teoretic, cât și experimental, a unor tehnici de înaltă rezoluție pentru a genera profilele sintetice de distanță ale unor ținte, precum și proiectarea unor algoritmi eficienți de reconstrucție a imaginii radar a unei ținte, totul în ideea implementării unor aplicații complexe de recunoaștere a formelor.

Trebuie amintit și faptul că, rezultatele științifice majore obținute în contextul procesării semnalelor HRR au fost fundamentate și pe cele două proiecte de cercetare naționale câștigate prin competiție, în care am fost implicat ca și membru în echipa de lucru. De asemenea, am publicat peste 10 articole în acest sens, dintre care 7 (5 ca autor principal) în diferite reviste indexate ISI sau proceedings-urile unor conferințe ISI CPCI.

Fuziunea modelelor conexioniste standard cu unele teorii matematice relativ recente a avut ca prim efect, o dezvoltare explozivă atât la nivel teoretic, cât și experimental, a unor arhitecturi robuste de tip neuro-fuzzy-genetice. În acest domeniu de cercetare încă promițător, activitatea mea a fost focalizată în principal, pe investigarea unor noi tipuri de modele AI hibride, cu o atenție sporită acordată teoriei sistemelor de tip GANN și respectiv, implementării hardware a acestora. Prin urmare, în cadrul lucrării de față au fost propuși și descriși în detaliu doi algoritmi genetici dedicați asigurării unui proces de instruire complet pentru o rețea neuronală RBF (un sistem de tip GARBF) și respectiv, feedforward/MLP (un sistem de tip GAML). De asemenea, a fost realizat un studiu comparativ între abordările curente bazate pe utilizarea tehnologiei FPGA și unele soluții neuro-hardware standard.

Rezultatele științifice relevante obținute în investigarea modelelor AI hibride au fost generate în cadrul a patru proiecte de cercetare naționale, toate câștigate prin competiție, în care am fost implicat ca membru în echipa de lucru. În acest context, am publicat peste 15 articole, dintre care 10 (8 ca autor principal) în diferite reviste indexate ISI sau proceedings-urile unor conferințe ISI CPCI. În plus, am fost autor unic pentru trei cărți, importante ca exemplu, conceptul NCW). În acest domeniu de cercetare am publicat peste 25 de articole, dintre care 15 (10 ca autor principal) în diferite reviste indexate ISI sau proceedings-urile unor conferințe ISI CPCI.

În general, activitatea mea de cercetare științifică în domeniul EW ar putea fi împărțită în două direcții majore, și anume: activitatea publicistică și respectiv, cea de cercetare proprie-zisă. Pentru început este foarte important de știut faptul că, în literatura de limbă română există o lipsă acută de informații curente în domeniul tehnic asociat EW. Din acest punct de vedere, activitatea mea publicistică obținută în urma unui proces îndelungat de documentare științifică în acest domeniu este una, în opinia mea, semnificativă. Astfel, trebuie amintit faptul că în calitate de unic autor, am elaborat două cărți de referință în domeniu (foarte important, un demers, cu puțin până în momentul de față, unic in literatura română în domeniul EW). De asemenea, tot în calitate de unic autor, am publicat două cărți, iar în calitate de co-autor, o carte, toate extrem de utile în înțelegerea unor aspecte teoretice și practice esențiale ale EW.

Cercetarea științifică proprie-zisă în domeniul EW a fost concretizată atât în calitate de director de proiect pentru trei proiecte derulate în programul de cercetare al Ministerului Apărării Naționale, cât și ca membru în echipa de lucru a două proiecte, în cadrul aceluiași program. De asemenea, este important de menționat că am fost implicat în peste dousprezece proiecte naționale câștigate prin competiție, ca membru în echipa de lucru.

O altă direcție de interes în domeniul EW a fost legată de necesitatea înțelegerea conexiunilor complexe între acesta și alte concepte moderne ale câmpului de luptă actual (spre exemplu, conceptul NCW). În acest domeniu de cercetare am publicat peste 25 de articole, dintre care 15 (10 ca autor principal) în diferite reviste indexate ISI sau proceedings-urile unor conferințe ISI CPCI.

Experiența consistentă și expertiza acumulată în aria EW mi-au permis să participe la activități specifice de standardizare și respectiv, achiziții pe linie militară. Prin urmare, am fost implicat, ca membru în echipa de lucru (2004-2008), în dezvoltarea sau acceptarea a patru standarde de tip MIL/STANAG. De asemenea, în anul 2010, am participat, în calitate de expert tehnic, într-un proces specific de achiziții de produse militare din domeniul EW în aviație.
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**List of acronyms**

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<th>Acronym</th>
<th>Description</th>
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<tr>
<td>AEW</td>
<td>Aviation EW</td>
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<tr>
<td>AI</td>
<td>Artificial Intelligence</td>
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<td>ALPR system</td>
<td>Automatic License Plate Recognition system</td>
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<td>AOA</td>
<td>Angle Of Arrival</td>
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<td>ARM</td>
<td>Antiradiation Missile</td>
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<td>BP rule</td>
<td>Back-Propagation rule</td>
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<td>Expert Selection data fusion</td>
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<td>MultiLayer Perceptron</td>
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<td>Mean Squared Error</td>
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<th>Definition</th>
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<td>Multistyle Training algorithm</td>
<td>NCW</td>
<td>Network Centric Warfare</td>
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<td>MUltiple SIgnal Classification algorithm</td>
<td>OCR system</td>
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<td>Neo-Fuzzy Neuron</td>
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<td>Neural Network</td>
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<td>OPTical INTeUgence</td>
<td>PCA</td>
<td>Principal Component Analysis</td>
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<td>Pattern Recognition</td>
<td>PSD function</td>
<td>Power Spectral Density function</td>
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<td>Polarimetric SAR</td>
<td>PST function</td>
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