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13. SUPPLEMENTARY NOTES

14. ABSTRACT

Substantial progress was made in analyzing the physical sources needed to realize pulsed-beam wavelets in practice. This was accomplished by extending classical potential theory to complex space-time, where point sources become distributions supported on disk-like dishes emitting pulsed beams. A careful and rigorous regularization method had to be devised for these distributions to be well defined. This also led to an explicit computation of the Fourier transform of pulsed-beam wavelets, which is expected to play an important role in computational methods based on the previously proposed generalized radar analysis. The viability of modeling reception, as well as emission, on pulsed-beam wavelets was proved by showing that the Green function, when extended analytically to complex observation points as well as complex emission points, can be sensibly interpreted as a coupling between transmitting and receiving dishes, both having pulsed-beam transmission- and reception patterns. A start was made toward understanding the current densities needed to produce *electromagnetic* pulsed-beam wavelets by computing the rotating current density necessary to produce holomorphic Coulomb fields.

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: U | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON Gerald Kaiser |
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FINAL REPORT
Feb 1, 1998 -- Nov 30, 2000

Gerald Kaiser

CONTRACT TITLE:
Development, Study and Applications of Causal Directed Electromagnetic Wavelets

AFOSR Contract # F49620-98-C-0013

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[List Co-PIs/Subcontractors, if any]
Subcontractors:

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Tel Aviv 69978, Israel

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OBJECTIVES
[List the original objectives (preferably in bulletized form) of the research effort or the statement of work. State new or revised objectives if they have changed and the reason why.]

A. Original Objectives:

1. Study in detail the application of pulsed-beam wavelets (PBW) to radar via the ambiguity/error functional formalism, with special attention to its practical implementation.

2. Search for alternate causal directed EM wavelets possessing a simple Fourier representation, thus lending themselves more easily to computations.

3. Find and interpret all transformations which map such wavelets into one another by acting on the parameters associated with the wavelets. Aside from rotations and space-time translations, these should include Lorentz transformations, which boost the wavelets to moving reference frames (thus making them useful for analyzing moving targets and platforms), and possibly special conformal transformations (which could be used to focus the wavelets).

4. Perform numerical and graphical studies of the various wavelets to help their visualization and interpretation.

5. If an improved family of wavelets is found as in (1b), apply them to radar via the ambiguity/error functional formalism. The existence of a large transformation group as in (1c) means that the associated model of radar is accordingly flexible since it includes such operations as tracking, scanning, and focusing.

B. Objective added during contract period:

6. Study the feasibility of hardware realizations of pulsed-beam wavelets.

Reason: To maximize the effectiveness of the generalized radar analysis based on ambiguity and error functionals, it is necessary to be able to realize PBW in hardware (at least approximately).

STATUS OF EFFORT

[A brief statement of progress towards achieving the research objectives. Please make this substantive (Limit to 200 words).]

1. I found a very general and natural method to construct PBW based on an analytic extension of classical potential theory based on the notion of "complex distance." Recently I found that this approach leads to an explicit and simple computation of the full Fourier transform of PBW, thus fullfilling one of the main objectives in the project. This appeared as a chapter titled "Potential theory and hyperbolic equations" in the book "Clifford Analysis," edited by J. Ryan and W. Sproessig, Birkhauser-Boston, July, 2000.

2. In preparing the short course "Radar Analysis with Causal Pulsed-Beam Wavelets" for EuroEM 2000, I was able to substantially develop the original PBW reception model. In particular, I confirmed that the coupling between a PBW emitter and a PBW receiver has the correct properties, being maximal when the two beams are highly focused, synchronised, and in pitch-catch configuration. I also showed that the

directivity function is convex, giving an upper limit on the coupling as a sum of the emission and receiving directivities.

3. I wrote a paper with Heyman (JASA Vol. 107, pp. 1880-1891, 2000) studying in detail the energy flow around and from a complex-source dish and other issues related to the realization of PBW.

ACCOMPLISHMENTS/NEW FINDINGS

[Describe research highlights, their significance to the field, their relationship to the original goals, their relevance to the AF's mission, and their potential applications to AF and civilian technology challenges.]

1. As a result of the work described in "Potential theory and hyperbolic equations," I now have an explicity form for the Fourier transform of PBW. The significance of this is as follows: In the generalized radar analysis, PBW are convolved with time signals along the motions of radar platforms or the targets to give "dynamical wavelets" encoding these motions. Such convolutions are most easily computed in the Fourier domain.

2. The convexity of the directivity function is a important and intuitive property, stating that the directivity of the transmission process is bounded by the sum of the directivities of the emitting and receiving dishes. This supports the correctness of the coupling model. Since convexity is a powerful mathematical tool, it should also prove useful in the further development of generalized radar analysis.

3. Recently I have succeeded in computing the exact (distributional) the charge-current density responsible for the so-called "holomorphic Coulomb field," which has appeared in the physics literature at least since 1973 (T. Newman, Maxwell's equations in complex Minkowski space, J. Math. Phys. 14, 1973, 102). Although this is a static EM field, it is closely related to PBW. The associated current density was postulated by Newman to be a circulating around the source disk, but neither he nor Iwo Bialynicki-Birula (an eminent physicist at the Polish Academy of Sciences) were able to give an explicit expression for it. After meeting with Bialynicki-Birula in Warsaw in October 2000, I was able to apply my regularization method and confirm Newman's postulate. This should serve as a model for the current density needed to realize electromagnetic pulsed-beam wavelets, one of the main objectives of the project.

PERSONNEL SUPPORTED

[List professional personnel supported by and/or associated with the research effort.]

1. Ehud Heyman
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Tel Aviv 69978, Israel

2. Louis Rossi
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PUBLICATIONS
[List peer-reviewed publications submitted and/or accepted during the 12-month period starting the previous 1 August (or since start for new grants).]

"Potential theory and hyperbolic equations, " a chapter in "Clifford Analysis," edited by J. Ryan and W. Sproessig, Birkhauser-Boston, July, 2000.

"Physical source realization of complex-source pulsed beams" (with E. Heyman and V. Lomakin)
J. of the Acoustical Society of America, Vol. 107, pp. 1880-1891, 2000.

BOOK IN PREPARATION:
"Physical Wavelets and Wave Equations,"
Progress in Mathematical Physics book series, Birkhauser-Boston, 2002.

INTERACTIONS/TRANSITIONS
Participation/Presentations At Meetings, Conferences, Seminars, Etc.
[Be selective, but be sure to include participations that reflect the quality/impact of the effort]

A. Conferences:

1. Communications via holomorphic Green functions, NATO Advanced Research Workshop on Clifford Analysis and its Applications, Prague, October 30 - November 3, 2000. (Proceedings to be published by Plenum Press.)

2. Pulsed-beam wavelets, Keynote Address at the Second International Congress of Electromechanical and Systems Engineering, Instituto Politecnico Nacional, Mexico City, October 25-29, 1999.

3. Highly focused pulsed-beam wavelets, Radar Processing, Technology, and Applications IV, SPIE Conference Proceedings #3810, Denver, CO, July 21-22, 1999.

4. Pulsed Beams and Physical Wavelets in Acoustics and Electromagnetics, Minisymposium presented jointly with E. Heyman and B.Z. Steinberg at the Fourth International Congress on Industrial and Applied Mathematics, Edinburgh, Scotland, July 5-9, 1999.

5. Potential Theory based on Complex Distance, invited talk, 5th International Conference on Clifford Algebras and their Applications in

Mathematical Physics, Ixtapa-Zihuatanejo, MEXICO, June 27-July 4, 1999.

6. Directed electromagnetic wavelets, in Intense Microwave Pulses VI, SPIE Conference Proceedings #3702, Orlando, FL, April, 1999.

7. New results on pulsed-beam wavelets, invited paper, in Wavelet Applications VI, SPIE Conference Proceedings #3723, Orlando, FL, April, 1999.

8. Electromagnetic pulsed-beam wavelets for radar, Invited paper, 28th European Microwave Conference, Amsterdam, October 5-9, Miller Freeman, 1998.

9. Wavelet analysis as a wideband generalization of time-frequency analysis, Invited paper, 136th Meeting of the Acoustical Society of America, JASA Vol. 104 #3, September 1998.

10. Recovery of Kolmogorov statistics in thermal mixing in the troposphere: The hazards of real data (with L. Rossi and D. Washburn), in Airborne Laser Advanced Technology, SPIE Conference Proceedings #3381, Orlando, FL, April, 1998.

B. Seminars:

October 25, 2000: Institute of Theoretical Physics, Polish Academy of Sciences, Warsaw: Pulsed-Beam Wavelets and Wave Equations. Interacted with Iwo Bialynicki-Birula, who explained the importance of understanding the current density generating the holomorphic Coulomb field.

1. October 10, 2000: Universite de Paris 6: Pulsed-Beam Wavelets and Wave Equations.

2. May 17, 2000: CWI (Center for Computer Science), Amsterdam: Pulsed-Beam Wavelets and Wave Equations.

3. April 13, 2000: Courant Institute of Mathematical Sciences, NYU, Complex-Distance Potential Theory and Hyperbolic Equations.

4. April 7, 2000: Talk given by invitation at the University of Texsas, Austin, on Complex-Distance Potential Theory and Hyperbolic Equations. Interacted there with Dr. Richard Matzner, Director of the Center for Relativity, regarding the connection between PBW and Kerr black holes.

5. March 3-9, 2000: Four lectures at Louisiana State University, Mathematics and Physics Departments, Pulsed-Beam Wavelets, Complex-Distance Potential Theory and Hyperbolic Equations.

6. October 25, 1999: Keynote Address, International Congress of Electromechanical and Systems Engineering, Instituto Politecnico

Nacional, Mexico City, Pulsed-beam wavelets.

7. September 24, 1999: University of Rochester, Complex-Distance Potential Theory and Hyperbolic Equations.

* Consultative And Advisory Functions To Other Laboratories And Agencies
[Consultative and advisory functions to other laboratories and agencies, especially Air Force and other DoD laboratories. Provide factual information about the subject matter, institutions, locations, dates, and name(s) of principal individuals involved.]

Short Courses:

1. Nov 13-16, 2000: A Detailed Introduction to Wavelets
with Applications to Image Analysis and Lossless Coding
The Virginia Center for Signals and Waves.
Participants included Dr. Doyle Dingus, AAC/WPC, Eglin AFB.

2. May 29, 2000: Radar Analysis with Causal Pulsed-Beam Wavelets
EuroElectromagnetics (EUROEM) 2000 Conference, Edinburgh, Scotland.
Participants included:
Col. James Taylor, USAF Ret. (ultrawideband radar specialist)
Walter Scott, Defense Threat Reduction Agency, Alexandria, VA.
Hans Schantz, Time Domain Corp., Huntsville, AL
Tim Payment, Time Domain Corp., Huntsville, AL
Xavier Mayurama, Physics Dept., Naval Postgraduate School, Monterey, CA
Gauthier Sylvain, Defense Reseqrch Establishment, Ottawa, Canada

3. May 1-4, 2000: Short course: A Detailed Introduction to Mathematical and Physical Wavelets (18 hours), Applied Technology Institute, Newport, RI.
Participants included:
Kevin Fitzpatrick, Naval Underwater Warfare Center, Newport, RI
Ronald Morrisey, Naval Underwater Warfare Center, Newport, RI
Nancy Dimarzio, Naval Underwater Warfare Center, Newport, RI
Joseph Putera, Naval Underwater Warfare Center, Newport, RI
Jessica Ward, Naval Underwater Warfare Center, Newport, RI
Mark Mulvey, ATEC, Inc., San Diego, CA
Shawn Strange, ATEC, Inc., San Diego, CA
Charles Valentine, Alacoron Corp., Nashua, NH

4. Nov 29-Dec 2, 1999: Short course: A Detailed Introduction to Mathematical and Physical Wavelets, Applied Technology Institute, Arlington, VA.
Participants included:
Edward Bosh, US Army Transportation Center, Alexandria, VA
Kaleb Benai, ONI, Washington, DC
Christopher Braun, MRSL, Sarasota, FL

Timothy Case, Allied signal Corp., Columbia, MD
Joseph Oulette, Litton/PRC, El Segundo, CA
June Watanabe, Litton/PRC, Los Angeles, CA

5. Sept 20-23, 1999: A Detailed Introduction to Wavelets, in-house at Eastman Kodak Company, Rochester, NY. 32 participants.

6. March 8-11, 1999: A Detailed Introduction to Mathematical and Physical Wavelets, Applied Technology Institute, Boston, MA
Paricipants included:
Thay Apran, DRECO National Defense, Ottawa, Canada
Derric Bouchard, Royal Military College of Canada, Kingston, Ontario
Lynn Herche, GLERL/NOAA, Ann Arbor, MI
Norman Lomas, Intelsat, Palo Alto, CA
Seppo Madekivi, Naval Research Institute, Helsinki, Finland

7. May 11-14/98: A Detailed Introduction to Mathematical and Physical Wavelets,
Given at the European Space Agency (ESA/ESTEC), Noordwijk, The Netherlands. 30 participants.

NEW DISCOVERIES, INVENTIONS, OR PATENT DISCLOSURES
[If none, report None.]

None

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