

# CARL R. CRAWFORD

## ADDRESS

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## EMPLOYMENT

CURRENT                    **CSUPTWO**, Milwaukee, Wisconsin  
Founder and President, July 2007 - Present

PREVIOUS                   **ANALOGIC CORPORATION**, Peabody, Massachusetts  
Technical Vice President, Corporate Imaging Systems, May 1995 - June 2007

**GENERAL ELECTRIC MEDICAL SYSTEMS**, Milwaukee, Wisconsin  
Senior Physicist, August 1983 - April 1995

**ELSCINT**, Haifa, Israel & Boston, Massachusetts  
Senior Computer Scientist; Mathematician, October 1981 - July 1983

## EDUCATION

GRADUATE                    **PURDUE UNIVERSITY**, West Lafayette, Indiana  
Ph.D., Electrical Engineering, May 1977 - December 1981

**PURDUE UNIVERSITY**, West Lafayette, Indiana  
M.S., Electrical Engineering, May 1976 - May 1977

UNDERGRADUATE           **PURDUE UNIVERSITY**, West Lafayette, Indiana  
B.S., Electrical Engineering, August 1973 - May 1976

## BOARD POSITIONS

PREVIOUS                    **SAN-TRON**, Ipswich, Massachusetts  
Member, Advisory Board  
January 2003 - February 2005

**ULTRASONIC SYSTEMS**, Amesbury, Massachusetts  
Member, Advisory Board  
January 2000 - January 2001

## ADJUNCT APPOINTMENTS

CURRENT	<b>NORTHEASTERN UNIVERSITY</b> , Boston, Massachusetts Adjunct Professor of Electrical and Computer Engineering September 2007 - Present
	<b>VIRGINIA TECH UNIVERSITY</b> , Blackburg, Virginia Adjunct Professor in School of Biomedical Engineering and Sciences January 2008 - Present
	<b>UNIVERSITY OF WISCONSIN</b> , Milwaukee, Wisconsin Clinical Instructor, College of Health Sciences, September 2008 - Present
PREVIOUS	<b>TEMPLE UNIVERSITY</b> , Philadelphia, Pennsylvania Adjunct Associate Professor of Diagnostic Imaging January 1996 - April 1998
	<b>UNIVERSITY OF WASHINGTON</b> , Seattle, Washington Affiliate Professor of Radiology May 1989 - April 1998
	<b>MEDICAL COLLEGE OF WISCONSIN</b> , Milwaukee, Wisconsin Adjunct Professor of Radiology July 1990 - January 1996

## WRITINGS

PATENTS*	United States Issued: 82 United States Allowed: 1 United States Pending: 4 International: 77 Total: 164
SPECIFICATIONS	Analogic: 89
REPORTS	Analogic: 411 General Electric: 187 Elscont: 43 Total: 641
ARTICLES	Journal: 23 Abstracts: 4
PRESENTATIONS	Conference: 62 Invited: 25

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\* Additional information about Carl Crawford's inventions can be found in the following book: "Juice: The Creative Fuel That Drives World-Class Invention," Evan I. Schwartz, *Harvard Business School Press*, pp. 103-109, 2004. A reprint can be found at: [www.csuptwo.com/juice.pdf](http://www.csuptwo.com/juice.pdf).

## PROFESSIONAL

MEMBERSHIP           Institute of Electrical and Electronic Engineers, Fellow  
American Association of Physicists in Medicine, Member  
Society of Nuclear Medicine, Member  
Society of Photo-Optical Instrumentation Engineers, Member

SERVICE               *IEEE Transactions on Medical Imaging*, Associate Editor  
December 1994 - Present  
*IEEE*, Milwaukee Section  
                            Vice-chair, January 2009 - December 2009  
                            Chair, January 2010 - December 2010  
*International Journal of Biomedical Imaging*, Associate Editor  
April 2005 - Present  
*Medical Physics*, Guest Associate Editor and referee  
January 1990 - Present

TRAINING             General Electric Managerial Skills Development Course  
December, 1994  
General Electric Project Leadership Course  
June, 1986

## PERSONAL

BIRTHDATE            August 29, 1956

BIRTHPLACE          Milwaukee, Wisconsin

CITIZENSHIP          USA

CLEARANCE            United States - Secret

LANGUAGES            Hebrew (conversational), French (beginning)

**REVENUE GENERATION**

<b>Project</b>	<b>Significance</b>	<b>Company</b>	<b>Role</b>	<b>Revenue (Millions)</b>
Helical medical CT scanning	Revitalized CT market; 100% replacement of non-helical scanners.	GE Medical	Inventor	\$1,000
Explosive detection algorithms. Reconstruction algorithms for multi-slice helical CT scanner.	World's first volumetric CT scanner for explosive detection	Analogic	Project engineer Inventor	\$250
Full field-of-view upgrade of explosive detection scanner	Created 2nd-generation product allowing customer to capture international market	Analogic	Project engineer	\$100
Transient noise suppressor for MRI scanner	Obviated expensive service calls	GE Medical	Inventor	\$50
Helical scanning for portable CT scanner	Allowed deployment of low-tier scan in mid-tier	Analogic	Project engineer Inventor	\$20
Three-dimensional display of CT data	Generated orthopedic application and increased sales of scanners	GE Medical	Project engineer Inventor	\$10
Iterative bone correction for CT scanner	Improved bone-brain interface allowing more sales for neurological applications	Elscent	Project engineer Inventor	\$2
Dual-energy explosive detection scanner	Reduced false alarm rate of scanners	Analogic	Project engineer Inventor	\$5
Explosive detection scanner for carry-on luggage	Detection of explosives at portals	Analogic	Project engineer Inventor	\$75
<b>Total</b>				<b>\$1,512</b>

## **EMPLOYMENT HISTORY**

### **CSUPTWO, Milwaukee, Wisconsin**

**July 2007 - present**

Csuptwo is a consulting practice specializing in medical imaging, Homeland Security, and product development.

Csuptwo specializes in the following modalities: computerized tomography (CT), magnetic resonance imaging (MRI), single photon emission tomography (SPECT), positron emission tomography (PET), and ultrasound imaging (U/S), dual energy imaging and automated threat detection algorithms based on computer aided detection (CAD).

Csuptwo specializes in the following aspects of product development: systems design, risk identification and mitigation, physics, signal and image processing, reconstruction algorithms and on-line implementations, and project leadership.

Present and past clients include (note that some clients do not want to be identified):

- Booz Allen Hamilton
- Department of Homeland Security
- GE Healthcare
- Inixtu
- Lawrence Livermore National Laboratory
- Northeastern University
- Samplify Systems
- Toshiba Medical Systems

### **ANALOGIC CORPORATION, Peabody, Massachusetts**

**May 1995 - June 2007**

Employed as Technical Vice President, Corporate Imaging Systems, reporting primarily to Bernard M. Gordon, Chairman of the Board and Chief Executive Officer and John W. Wood, President and Chief Executive Officer. Responsible for physics, mathematics, systems engineering, image quality, system integration, reconstruction software, and service tools for medical and industrial CT scanners. Managed (four positions) of the following functions: Imaging Sciences for Medical CT, Imaging Sciences for Security, Reconstruction Software for Medical CT and Reconstruction Software for Security. Leadership included approximately twenty direct reports including both individual contributors and intermediate managers, mainly PhDs. In addition, provide technical support for mergers and acquisitions.

Standard deliverables for the products included: marketing and engineering requirement specifications (review for acceptable image quality); reconstruction requirement specifications (write and verify with scanner simulations); algorithm development; image quality predictions; scanner integration for first prototypes; reconstruction hardware (write specifications and choose hardware); on-line reconstruction software; verification and validation of on-line codes; support manufacturing and field service; automated image quality assessment; and automated threat (explosives, guns, knives) detection algorithms and software.

The following CT scanners were developed:

- Medical CT Scanners

## **EMPLOYMENT HISTORY** (continued)

- Portable (Philips, Tomoscan)
- Mid-tier (Philips, Aura)
- Low-cost (Siemens, Smile)
- CT for PET/CT (Photodetection Systems)
- 16-slice (Hitachi)
  
- Explosive Detection CT Scanners
  - Volumetric scanner (L-3 Communications, eXaminer)
  - Full field-of-view upgrade (L-3 Communications, eXaminer)
  - Dual energy model (L-3 Communications, eXaminer)
  - Carry-on inspection scanner (Analogic, Cobra)
  - Low-cost checked baggage (L-3 Communications, Argus)
  - Low-cost checked baggage (Perkin Elmer, Argus)
  - Large bore (Analogic, XLB)

The following is a summary of major research and development activities, both through his own technical work and through his leadership of direct and indirect reports from a wide range of technical disciplines.

### Management:

- Program manager for full field-of-view upgrade to initial security scanner leading to approximately \$100 million in incremental revenue.
- Program manager for helical scanning version of portable CT scanner.
- Functional manager for imaging sciences and reconstruction software for medical and security.

### Invention:

- 50 U.S. Patent Applications; 37 used in products.
- 411 technical reports.
- 89 product specifications.
- Helical scanning for asymmetric CT scanners; used in two models of medical CT scanners.
- Nutating slice reconstruction for cone-beam CT; used in explosive detection CT scanners.
- Automatic explosive detection algorithms; certified by FAA.
- Automatic image quality assessment for CT scanners.
- Dual energy CT algorithms foundation of two grants received by Analogic to develop next generation scanners.

### Customer Utilization:

- Portable CT scanner's image quality exceeded expectations; sold as higher-tier scanner.
- Helical scanning increased market for portable CT scanner.
- Mid-tier CT scanner's image quality meets customer expectations.
- Explosive detection CT scanner certified with Analogic's automatic detection algorithms; over 600 scanners deployed.
- Full field-of-view upgrade enhanced reputation of original scanner allowing customer to dominate market.
- Dual energy scanner certified by the TSA with lowest false alarm rate in the industry.

## **EMPLOYMENT HISTORY** (continued)

### **SAN-TRON, Ipswich, Massachusetts**

**January 2003 - February 2005**

Member of external advisory board having the objective to grow the business based on RF connector technology. Primary responsibilities include product development and management. Implemented an action-driven leadership program.

### **ULTRASONIC SYSTEMS, Amesbury, Massachusetts** **January 2000 - January 2001**

Member of external advisory board having the objective to grow the business based on ultrasonic spray technology. Primary responsibilities include product development and management. The following is a summary of the present growth path.

- Expand the existing business in spray fluxing for OEM and retrofit customers.
- Develop new spraying applications.

### **GE MEDICAL SYSTEMS, Milwaukee, Wisconsin**

**August 1983 - April 1995**

Employed as a Senior Physicist in the computed tomography (CT) division of the Applied Science Laboratory through 1989. The following is a summary of major research and development activities, which have led to 31 United States patents.

- Developed methods for scanning with simultaneous patient translation (helical or spiral scanning), which doubled the scan rate and facilitated new protocols such as CT angiography. Generated an estimated \$1 billion in incremental revenue.
- Resolved the requirements for slip-ring architectures to enable the implementation of commercially and clinically viable scanners.
- Developed an interactive three-dimensional display package using a rapid prototyping process to meet aggressive cost and resource targets. Extended this technology to allow the mathematical disarticulation of joints.
- Developed a mathematical model of the spatial dependence of resolution and noise, which allowed cost-reduced data acquisition systems and one second scanners.
- Devised reconstruction algorithms for single photon emission computed tomography (SPECT) using fan-beam projections with a displaced center of rotation, allowing for the direct reconstruction of projections on a commercial scanner.
- Coded a graphics package and an image display program to support development of algorithms for the above projects.

Primary responsibilities, from the beginning of 1990, have been the algorithmic and systems aspects of magnetic resonance imaging (MRI) while working as a Senior Physicist in the MRI division of the Applied Science Laboratory. The following is a summary of key accomplishments.

- Identified the sources of radio frequency emissions (white pixels or spike noise), which increased the yield of a high speed scanner from zero to 100 percent. This was accomplished by assembling a five person team that disassembled a prototype scanner and determined usable component combinations. The work resulted in a design guide for future scanners.
- Invented and reduced to practice an inexpensive device to detect and eliminate rf emissions before they entered the scanner electronics, eliminating a \$3 million per year maintenance cost.

## **EMPLOYMENT HISTORY** (continued)

- Led a six member team to identify and reduce risk in a new high speed scanner, allowing the scanner to be shipped on time and fully featured.
- Developed a new method to improve the quality of partial Fourier imaging techniques, improving the quality of MR angiograms in regions of susceptibility such as the sinuses.
- Investigated a combined gradient and spin echo imaging (GRASE) sequence, which adds susceptibility contrast to Fast Spin Echo imaging.
- Managed a department research scanner that supports the development of new imaging protocols and hardware.

### **ELSCINT, Haifa, Israel**

**June 1982 - July 1983**

Employed as a CT specialist reporting directly to the head of the research and development group in the radiology division. Handled mathematical aspects of the CT scanner in the framework of a consultant to the physics, software, and mechanical and electrical engineering groups. The following is a summary of major research and development activities, which have led to four United States patents.

- Invented a new interpolation method for fan-beam CT resorting algorithms, to avoid paying patent royalties.
- Developed a high speed reprojection method using a modified back-projector so that a two-pass polychromatic correction algorithm could execute in clinically acceptable times.
- Wrote a cross-assembler for bit-slice processors, enabling faster development of micro-code for dedicated reconstruction computers.

### **ELSCINT INC., Boston, Massachusetts**

**October 1981 - June 1982**

Worked in the CT research and development department. The following is a summary of major research and development activities, which led to one United States patent.

- Developed methods to reduce the level of image degradation caused by noncoplanarity.
- Directed a team that built a noncoplanar scanner from an existing coplanar machine in order to verify computer simulations of noncoplanarity.
- Simulated the data acquisition system in a cardiac CT scanner to determine its manufacturing tolerances.

## PATENTS

- [1] Shimoni, Y., Netter, Z., and Crawford, C. R., "Equipment and methods of rearranging divergent beams," Assignee: Elscint Inc., United States: 4,570,224, February 11, 1986, France: 2,536,862, June 1, 1984, Netherlands: 8,304,091, June 18, 1984, Germany: 3,342,975, June 20, 1984, Israel: 70,212, March 31, 1987.
- [2] Crawford, C. R., and Reuveni, A., "A system of reprojecting images acquired by backprojection," Assignee: Elscint Ltd., United States: 4,626,991, December 2, 1986, Germany: 3,414,875, October 25, 1984, France: 2,544,939, October 26, 1984, Netherlands: 8,401,237, November 16, 1984, Israel: 71,561, March 31, 1987.
- [3] Crawford, C. R., "A system of reprojecting images using transform techniques," Assignee: Elscint Ltd., United States: 4,616,318, October 7, 1986, Germany: 3,420,576, February 7, 1985, France: 2,547,439, December 14, 1984, Netherlands: 8,401,684, January 2, 1985.
- [4] Crawford, C. R., and Freunlich, D., "An improved reprojection system," Assignee: Elscint Ltd., United States: 4,714,997, December 22, 1987, Germany: 3,420,575, January 17, 1985, France: 2,547,149, December 7, 1984, Netherlands: 8,401,739, January 2, 1985, Israel: 72,936, November 30, 1987.
- [5] Crawford, C. R., Barnea, D., Sohval, B., and Shimoni, Y., "System and methods for correcting noncoplanarity artifacts," Assignee: Elscint Ltd., United States: 4,578,753, March 25, 1986, Germany: 3,429,155, April 18, 1985, France: 2,551,211, March 1, 1985, Netherlands: 8,402,630, March 18, 1985, Israel: 72,663, October 31, 1988.
- [6] Gullberg, G. T., and Crawford, C. R., "Method and means of correcting for a shift in the center of rotation of a rotating fan beam CT system," Assignee: General Electric Medical Systems, United States: 4,703,424, October 27, 1987, Germany: 3,546,233, July 31, 1986.
- [7] Crawford, C. R., and Acharya, K. C., "Apparatus for reduction of filtration truncation errors," Assignee: General Electric Medical Systems, United States: 4,606,004, August 12, 1986, Germany: 3,509,777, September 26, 1985, Israel: 74,566, August 15, 1989.
- [8] Crawford, C. R., "Improved method and apparatus for back projection image reconstruction using virtual equi-spaced detectors," Assignee: General Electric Medical Systems, United States: 4,636,952, January 13, 1987.
- [9] Crawford, C. R., "Method and apparatus for imaging in the presence of multiple high density objects," Assignee: General Electric Medical Systems, United States: 4,709,333, November 24, 1987.
- [10] Gullberg, G. T., and Crawford, C. R., "Method and means of correcting for a shift in the center of rotation of a rotating fan beam CT system," Continuation in part of [6], Assignee: General Electric Medical Systems, United States: 4,812,983, March 14, 1989.
- [11] Crawford, C. R., and Lorensen, W. E., "Apparatus and method for improvement of 3D images derived from tomographic data," Assignee: General Electric Medical Systems, United States: 4,831,528, May 16, 1989. Europe: 316,135, May 17, 1989, Israel: 87,511, March 29, 1992.
- [12] Crawford, C. R., "Minimization of directed points generated in three-dimensional dividing cubes method," Assignee: General Electric Medical Systems, United States: 4,885,688, December 5, 1989, Europe: 318,292, May 31, 1989, Israel: 87,963, March 29, 1992, Canada: 1,315,902, April 6, 1993.
- [13] Crawford, C. R., Frazee, D. M., and Santos, E., "Rapid processing of three-dimensional graphical objects from tomographic data," Assignee: General Electric Medical Systems, United States: 4,868,748, September 19, 1989, Europe: 318,293, May 31, 1989, Israel: 87,964, May 5, 1992.

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- [14] Crawford, C. R., "Image magnification to reduce rendering times of three-dimensional images," Assignee: General Electric Medical Systems, Europe: 318,291, May 31, 1989, Japan: 2,001,083, January 5, 1990, Israel: 87,966, July 15, 1992.
- [15] Crawford, C. R., Karr, S. G., Welles, K. B., O'Donnell, M., and Pelc, N. J., "Method and apparatus for coherent imaging system," Assignee: General Electric Medical Systems, United States: 5,005,419, April 9, 1991, Germany: 3,918,815, December 12, 1989.
- [16] Crawford, C. R., "Three-dimensional surface representation using connectivity method without leaks," Assignee: General Electric Medical Systems, United States: 4,905,148, February 27, 1990, Europe: 354,026, February 2, 1990.
- [17] Crawford, C. R., "Three-dimensional object removal via connectivity," Assignee: General Electric Medical Systems, United States: 4,903,202, February 20, 1990.
- [18] Crawford, C. R., "Three-dimensional images obtained from tomographic data using a variable threshold," Assignee: General Electric Medical Systems, United States: 4,914,589, April 3, 1990, Europe: 366,387, May 2, 1990, Israel: 366,387, March 25, 1992.
- [19] Crawford, C. R., "Three-dimensional images obtained from tomographic data having unequally spacing slices," Assignee: General Electric Medical Systems, United States: 4,953,087, August 28, 1990.
- [20] Crawford, C. R., "Three-dimensional images obtained from tomographic slices with gantry tilt," Assignee: General Electric Medical Systems, United States: 4,989,142, January 29, 1991.
- [21] Crawford, C. R., and Pelc, N. J., "Method for reducing motion induced artifacts in projection imaging," Assignee: General Electric Medical Systems, United States: 4,994,965, February 19, 1991, Europe: 370,341, May 30, 1990, Israel: 92,115, May 13, 1993.
- [22] Crawford, C. R., "Method for reducing skew image artifacts in helical projection imaging," Assignee: General Electric Medical Systems, United States: 5,046,003, September 3, 1991, Europe: 405,862, January 2, 1991, Canada: 2,010,136, December 20, 1990, Israel: 94,714, May 5, 1993.
- [23] Crawford, C. R., and Frazee, D. M., "Three dimensional disarticulation," Assignee: General Electric Medical Systems, United States: 5,150,427, September 22, 1992, Europe: 420,546, April 3, 1991, Canada: 2,014,907, March 29, 1992, Israel: 95,648, April 12, 1994.
- [24] King, K. F., Lonn, A. H. R., and Crawford, C. R., "Computerized tomographic image reconstruction method for helical scanning," Assignee: General Electric Medical Systems, United States: 5,270,923, December 14, 1993, Europe: 426,464, May 8, 1991, Canada: 2,021,624, May 3, 1991.
- [25] King, K. F., and Crawford, C. R., "Extrapolative reconstruction method for helical scanning," Assignee: General Electric Medical Systems, United States: 5,233,518, August 3, 1993, Europe: 428,348, May 22, 1991, Israel: 96,212, September 22, 1993.
- [26] King, K. F., and Crawford, C. R., "Method for helical scanning with a stationary detector using rebinning and splicing to create detector vertex projection sets," Assignee: General Electric Medical Systems, United States: 5,208,746, May 4, 1993, Europe: 430,550, June 5, 1991, Canada: 2,021,621, May 23, 1991.
- [27] Crawford, C. R., and King, K. F., "Method for fan beam helical scanning using rebinning," Assignee: General Electric Medical Systems, United States: 5,216,601, June 1, 1993, Europe: 430,549, June 5, 1991, Canada: 2,021,623, May 23, 1991.

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- [28] Crawford, C. R., and King, K. F., "Method for reducing patient translation artifacts in tomographic imaging," Assignee: General Electric Medical Systems, United States: 5,170,346, December 8, 1992, Europe: 430,506, June 5, 1991, Israel: 96,318, September 22, 1993, Netherlands: 8,401,684, January 2, 1985.
- [29] King, K. F., and Crawford, C. R., "Compensation of computed tomography data for x-ray detector afterglow artifacts," Assignee: General Electric Medical Systems, United States: 5,265,013, November 23, 1993, Europe: 487,243, May 27, 1992, Canada: 2,048,782, May 20, 1992.
- [30] Toth, T. L., King, K. F., and Crawford, C. R., "Helical scanning computed tomography with tracking x-ray source," Assignee: General Electric Medical Systems, United States: 5,090,037, February 18, 1992, Europe: 487,245, May 5, 1992, Canada: 2,048,741, May 20, 1992, China: 1,061,524, June 3, 1992.
- [31] Crawford, C. R., "Motion artifact reduction in projection imaging," Assignee: General Electric Medical Systems, United States: 5,251,128, October 5, 1993, Germany: 4,137,652, May 21, 1992, Great Britain: 2,250,164, May 27, 1992.
- [32] Hu, H., Crawford, C. R., Pfoh, A. H., and Hsieh, J., "Tomographic image reconstruction using cross-plane rays," Assignee: General Electric Medical Systems, United States: 5,396,528, March 7, 1995, Europe: 520,778, December 30, 1992.
- [33] Toth, T. L., Crawford, C. R., and King, K. F., "Deconvolution filter for CT system," Assignee: General Electric Medical Systems, United States: 5,361,291, November 1, 1994, Europe: 543,626, May 26, 1993.
- [34] Toth, T. L., King, K. F., and Crawford, C. R., "Helical scanning computed tomography apparatus with constrained tracking of the x-ray source," Assignee: General Electric Medical Systems, United States: 5,224,136, June 29, 1993.
- [35] Crawford, C. R., and Ritchie, C. J., "Localized motion artifact reduction in projection imaging," Assignee: General Electric Medical Systems, United States: 5,287,276, February 15, 1994.
- [36] Crawford, C. R., and Ritchie, C. J., "Correction of CT attenuation data using fan beam reprojections," Assignee: General Electric Medical Systems, United States: 5,438,602, August 1, 1995.
- [37] Crawford, C. R., Dallapiazza, D. G., Eash, M. G., Pelc, N. J., Small, D., Souza, S. P., and Stormont, R. S., "Detection and elimination of wide bandwidth noise in MRI signals," Assignee: General Electric Medical Systems, United States: 5,525,906, June 11, 1996.
- [38] Crawford, C. R., Ruth, C. R., Bachilov, Y., and Deych, R., "Multi-processor afterglow artifact correction filter for use with computed tomography scanners," Assignee: Analogic Corporation, United States: 5,644,610, July 1, 1997, Germany: 19781844.7-35, March 6, 2003, Holland: 1,006,359, February 15, 2000.
- [39] Ruth, C. R., Dobbs, J. M., and Crawford, C. R., "Method and apparatus for helical computed tomography scanning with asymmetric detector system," Assignee: Analogic Corporation, United States: 5,828,718, October 27, 1998, Taiwan: 101,512, February 11, 1999, Netherlands: 1,007,611, July 21, 1999, Japan: 3,609,425, October 22, 2004, China: ZL 97180040.5, September 8, 2004.
- [40] Larson, G., Ruth, C. C., and Crawford, C. R., "Nutating slice CT image reconstruction apparatus and method," Assignee: Analogic Corporation, United States: 5,802,134, September 1, 1998, Japan: 3,547,455, April 23, 2004.

**PATENTS** (continued)

- [41] Urchuk, S. N., Ruth, C. C., and Crawford, C. R., "Apparatus and method for computed tomography scanning using halfscan reconstruction with asymmetric detector system," Assignee: Analogic Corporation, United States: 5,848,117, December 8, 1998, Taiwan: 104,424, June 1, 1999, Japan: 3,660,586, March 25, 2005.
- [42] Schafer, D. A., Ruth, C. C., and Crawford, C. R., "Air Calibration Scan for Computed Tomography Scanner with Obstructing Objects," Assignee: Analogic Corporation, United States: 5,949,842, September 7, 1999.
- [43] Ruth, C. C., Crawford, C. R., and Weedon, H. J., "Computed Tomography Scanning Apparatus and Method with Temperature Compensation for Dark Current Offsets," Assignee: Analogic Corporation, United States: 5,970,113, October 19, 1999.
- [44] Ruth, C. C., and Crawford, C. R., "Computed Tomography Scanning Target Detection Using Non-Parallel Slices," Assignee: Analogic Corporation, Japan: 3585835, August 13, 2004, United States: 5,909,477, June 1, 1999.
- [45] Crawford, C. R., and Ruth, C. C., "Computed Tomography Scanning Target Detection Using Target Surface Normals," Assignee: Analogic Corporation, United States: 5,901,198, May 4, 1999.
- [46] Bailey, E. M., Crawford, C. R., Greenberg, A. I., and Ruth, C. C., "Parallel Processing Architecture for Computed Tomography Scanning System Using Non-Parallel Slices," Assignee: Analogic Corporation, Japan: 3585835, August 13, 2004, United States: 5,887,047, March 23, 1999.
- [47] Crawford, C. R., and Ruth, C. C., "Computed Tomography Scanning Apparatus and Method for Generating Parallel Projections Using Non-Parallel Slice Data," Assignee: Analogic Corporation, Japan: 3585835, August 13, 2004, United States: 5,881,122, March 9, 1999.
- [48] Gordon, B. M., Bailey, E. M., Schafer, D. A., Ruth, C. C., and Crawford, C. R., "Computed Tomography Scanning Apparatus and Method Using Adaptive Reconstruction Window," Assignee: Analogic Corporation, United States: 6,256,404, July 3, 2001.
- [49] Hiraoglu, M., Bechwati, I. M., Simanovsky, S., and Crawford, C. R., "Apparatus and Method for Detecting Sheet Objects in Computed Tomography Data," Assignee: Analogic Corporation, United States: 6,111,974, August 29, 2000.
- [50] Simanovsky, S., Hiraoglu, M., Bechwati, I. M., and Crawford, C. R., "Apparatus and Method for Eroding Objects in Computed Tomography Data," Assignee: Analogic Corporation, United States: 6,075,871, June 13, 2000.
- [51] Bechwati, I. M., Hiraoglu, M., Simanovsky, S., and Crawford, C. R., "Apparatus and Method for Combining Related Objects in Computed Tomography Data," Assignee: Analogic Corporation, United States: 6,128,365, October 3, 2000.
- [52] Simanovsky, S., Hiraoglu, M., Bechwati, I. M., and Crawford, C. R., "Apparatus and Method for Detecting Sheet Objects in Computed Tomography Data," Assignee: Analogic Corporation, United States: 6,026,143, February 15, 2000.
- [53] Bechwati, I. M., Hiraoglu, M., Simanovsky, S., and Crawford, C. R., "Apparatus and Method for Classifying Objects in Computed Tomography Data Using Density Dependent Mass Thresholds," Assignee: Analogic Corporation, United States: 6,076,400, June 20, 2000.

**PATENTS** (continued)

- [54] Bechwati, I. M., Hiraoglu, M., Simanovsky, S., and Crawford, C. R., "Apparatus and Method for Correcting Object Density in Computed Tomography Data," Assignee: Analogic Corporation, United States: 6,108,396, August 22, 2000.
- [55] Simanovsky, S., Hiraoglu, M., Bechwati, I. M., and Crawford, C. R., "Apparatus and Method for Density Discrimination of Objects in Computed Tomography Data Using Multiple Density Ranges," Assignee: Analogic Corporation, United States: 6,078,642, June 20, 2000.
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## CONFERENCE PRESENTATIONS (continued)

- [24] Godwin, J. D., Crawford, C. R., Stanford, W., and Traver, R. D., "Motion artifacts in chest CT," presented at the "74th Scientific Assembly of The Radiology Society of North America," Chicago, Illinois, November 27 - December 2, 1988. Abstract appeared in *Radiology*, Vol. 169(P), November 1988, p. 213.
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- [28] Crawford, C. R., Cline, H. E., Lorensen, W. E., and Teeter, B. C., "3-D Imaging Using Normalized Gradient Shading in CT and MRI," presented at the "SPIE Medical Imaging Conference," Newport Beach, California, January 29 - February 3, 1989. Paper appeared in conference proceedings, "SPIE Vol. 1091 Medical Imaging III: Image Capture and Display (1989)", pp. 294-300.
- [29] Crawford, C. R., Starshak, R. J., and Waisman, R. C., "Three-Dimensional Display of Mathematically Disarticulated Objects," presented at the "Computer Assisted Radiology Third International Symposium," Berlin, June 27, 1989. Paper appeared in *CAR'89 Computer Assisted Radiology*, Lemke, H. U., Rhodes, M. L., Jaffee, C. C., and Felix, R., Editors, Springer-Verlag, Berlin, 1989, pp. 348-354.
- [30] Crawford, C. R., Godwin, J. D., and Pelc, N. J., "Reduction of motion artifacts in computed tomography," presented at the "Eleventh annual international conference of the IEEE Engineering in Medicine and Biology Society," November 10, 1989, Seattle, WA. Paper appeared in conference proceedings, pp. 485-486.
- [31] Ritchie, C. J., Peterson, E., Yee, D., Kim, Y., Godwin, J. D., and Crawford, C. R., "A 3-D motion control system for simulation of CT motion artifacts," presented at the "Eleventh annual international conference of the IEEE Engineering in Medicine and Biology Society," November 10, 1989, Seattle, WA. Paper appeared in conference proceedings, pp. 487-488.
- [32] Crawford, C. R., and Lonn, A. H. R., "Iterative CT reconstruction using reprojection," presented (invited) at the "12th annual conference of the IEEE Engineering in Medicine and Biology Society," November 1-4, 1990, Philadelphia, Pennsylvania. Paper appeared in conference proceedings, pp. 368-369.
- [33] King, K. F., and Crawford, C. R., "CT Scanning With Simultaneous Patient Translation," presented at the "76th Scientific Assembly of The Radiology Society of North America," Chicago, Illinois, November 25 - 30, 1990. Abstract appeared in *Radiology*, Vol. 177(P), November 1990, p. 108.
- [34] Ritchie, C. J., Godwin, J. D., and Crawford, C. R., "Motion artifacts in computed tomography," presented at the "76th Scientific Assembly of The Radiology Society of North America," Chicago, Illinois, November 25 - 30, 1990. Abstract appeared in *Radiology*, Vol. 177(P), November 1990, p. 109.

## CONFERENCE PRESENTATIONS (continued)

- [35] Crawford, C. R., King, K. F., Ritchie, C. J., and Godwin, J. D., "Respiratory Compensation in Projection Imaging," presented at the "76th Scientific Assembly of The Radiology Society of North America," Chicago, Illinois, November 25 - 30, 1990. Abstract appeared in *Radiology*, Vol. 177(P), November 1990, p. 277.
- [36] Crawford, C. R., and King, K. F., "Simultaneous Patient Translation During CT Scanning," presented at the "SPIE Medical Imaging '91 Conference", San Jose, California, February 24 - March 1, 1991. Paper appeared in conference proceedings, pp. 203-213.
- [37] Hu, H., Lonn, A. H. R., Crawford, C. R., Pfoh, A. H., and Hsieh, J. "A problem of fully 3D tomographic reconstruction using partial-scanned data," presented at the "International Meeting on Fully Three-Dimensional Image Reconstruction in Nuclear Medicine and Radiology," Corsendonk, Belgium, July 3-5, 1991.
- [38] Myers, C. C., Crawford, C. R., Vavrek, R., and Roemer, P. B., "Gradient coil design for patient access," presented at the "Tenth annual meeting of the Society of Magnetic Resonance in Medicine," San Francisco, California, August 10-16, 1991. Paper appeared in conference proceedings, p. 709.
- [39] Bandettini, P. A., Wong, E. C., Crawford, C. R., and Hyde, J. S., "Selective averaging of multiple MR images," presented at the "Tenth annual meeting of the Society of Magnetic Resonance in Medicine," San Francisco, California, August 10-16, 1991. Paper appeared in conference proceedings, p. 737.
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- [41] Godwin, J. D., Ritchie, C. J., Hsieh, J., Gard, M. F., Crawford, C. R., Kim, Y., and Freeny, P. C. "CT motion artifacts: characterization and reduction," presented at the "Society of Computed Body Tomography and Magnetic Resonance," Tucson, Arizona, March 8, 1992.
- [42] Ritchie, C. J., Kim, Y., Crawford, C. R., and Godwin, J. D., "CT Motion Artifact Correction Using Pixel-Specific Back-Projection," presented at the "Fourteenth annual international conference of the IEEE Engineering in Medicine and Biology Society," October 31, 1992, Paris, France. Paper appeared in conference proceedings, pp. 1782-1783.
- [43] Ritchie, C. J., Godwin, J. D., Crawford, C. R., and Kim, Y., "Correction of respiratory motion artifacts in CT with pixel-specific backprojection," presented at the "77th Scientific Assembly of The Radiology Society of North America," Chicago, Illinois, November 30 - December 4, 1992. Abstract appeared in *Radiology*, Vol. 185(P), November 1992, p. 271.
- [44] Stearns, C. W., Crawford, C. R., and Hu, H., "Oversampled filters for quantitative volumetric PET reconstruction," presented at the "1993 International Meeting on Fully Three-Dimensional Image Reconstruction in Radiology and Nuclear Medicine," Snowbird, Utah, June 23-25, 1993.
- [45] Crawford, C. R., King, K. F., and Hu, H., "Fast reconstruction of overlapping slices using helical CT," presented at the "78th Scientific Assembly of The Radiology Society of North America," Chicago, Illinois, November 28 - December 3, 1993. Abstract appeared in *Radiology*, Vol. 189(P), November 1993, p. 217.
- [46] Ritchie, C. J., Hsieh, J., Gard, M. F., Godwin, J. D., Crawford, C. R., and Kim, Y., "CT motion artifact reduction with predictive respiratory gating," presented at the "78th Scientific Assembly of The Radiology Society of North America," Chicago, Illinois, November 28 - December 3, 1993. Abstract appeared in *Radiology*, Vol. 189(P), November 1993, p. 164.
- [47] Crawford, C. R., and Linz, A. M., "Correction of geometric distortion using bipolar gradients and polynomial basis functions," presented at the "First Meeting of the Society of Magnetic Resonance," Dallas, Texas, March 5-9, 1994. Abstract appeared in *Journal of Magnetic Resonance Imaging*, Vol. 4(P), Works in Progress Supplement, January/February 1994, p. S15.

## CONFERENCE PRESENTATIONS (continued)

- [48] Crawford, C. R., King, K. F., and Hu, H., "Helical CT noise reduction using optimized starting angles," presented at the "79th Scientific Assembly of The Radiology Society of North America," Chicago, Illinois, November 27 - December 2, 1994. Abstract appeared in *Radiology*, Vol. 193(P), November 1994, p. 170.
- [49] King, K. F., Crawford, C. R., and Maier, J. K., "Correction for filter-induced ghosts in EPI," presented at the "Third Meeting of the Society of Magnetic Resonance," Nice, France, August, 1995. Paper appeared in conference proceedings, p. 105.
- [50] King, K. F., Foo, T. K. F., and Crawford, C. R., "Gradient design considerations for spiral scanning," presented at the "Third Meeting of the Society of Magnetic Resonance," Nice, France, August, 1995. Paper appeared in conference proceedings, p. 623.
- [51] Crawford, C. R., Small, D. S., Dallapiazza, D. G., Eash, M. G., and Stormont, R. S., "Transient noise suppression using common mode detection and receiver blanking," presented at the "Third Meeting of the Society of Magnetic Resonance," Nice, France, August, 1995. Paper appeared in conference proceedings, p. 939.
- [52] King, K. F., Licato, P. E., Slayman, B. E., and Crawford, C. R., "Fast flip angle calibration" presented at the "Third Meeting of the Society of Magnetic Resonance," Nice, France, August, 1995. Paper appeared in conference proceedings, p. 699.
- [53] Crawford, C. R., Small, D. S., Dallapiazza, D. G., Eash, M. G., and Stormont, R. S., "Transient noise suppression using receiver blanking," presented at the "81st Scientific Assembly of The Radiology Society of North America," Chicago, Illinois, November/December 1995. Abstract appeared in *Radiology*, Vol. 197(P), November 1995, p. 355.
- [54] Crawford, C. R., Bernstein, M. A., King, K. F., Martin, J. D., Licato, P. E., and Foo, T. K. F., "Dependence of imaging performance on gradient system specifications," presented at the "81st Scientific Assembly of The Radiology Society of North America," Chicago, Illinois, November/December 1995. Abstract appeared in *Radiology*, Vol. 197(P), November 1995, p. 355.
- [55] Crawford, C. R., Ruth, C., and Timmer, J., "Helical scanning with an asymmetric detector array," presented at the "82st Scientific Assembly of The Radiology Society of North America," Chicago, Illinois, December 1996. Abstract appeared in *Radiology*, Vol. 201(P), December 1996, p. 189.
- [56] Woronoff, A. J., Boyko, O. B., Crawford, C. R., Akhtar, N., and Kochan, J. P., "Artifacts on CT and MR images and the diagnostic pitfalls in neuroimaging," presented at the "82st Scientific Assembly of The Radiology Society of North America," Chicago, Illinois, December 1996. Abstract appeared in *Radiology*, Vol. 201(P), December 1996, p. 452.
- [57] Karimi, S., Jackson, B., and Crawford, C. R., "Distributed Embedded Computing in the Detection of Explosives," presented at the "Sixth Annual High Performance Embedded Computing Workshop," Lexington, Massachusetts, September 2002. Paper appeared in conference proceedings, p. 127.
- [58] Crawford, C. R., Ying, Z., and Naidu, R., "Advances in volumetric dual energy x-ray computed tomography," presented at the Gordon Research Conference: "Detecting Illicit Substances: Explosives & Drugs," Les Diablerets, Switzerland, August 30, 2005.
- [59] Ying, Z., Naidu, R., Guilbert, K., Schafer, D., and Crawford, C. R., "Dual Energy Volumetric X-ray Tomographic Sensor for Luggage Screening," presented at "SAS 2007 - IEEE Sensors Applications Symposium, San Diego, California, February 6-8, 2007, Paper appeared in conference proceedings, IEEE Catalog Number: 07EX1546.
- [60] Naidu, R., Ulker Karbeyaz, B., Ying, Z., Simanovsky, S., Hirsch, M., Schafer, D., and Crawford, C. R., "Variable Pitch Tilted Slice Reconstruction Using John's Equation," presented at the 9th International Meeting on Fully Three-Dimensional Image Reconstruction in Radiology and Nuclear Medicine, Lindau, Germany, July 13, 2007.

**CONFERENCE PRESENTATIONS** (continued)

- [61] Song, S. M., Boyd, D. P., and Crawford, C. R., "Three-dimensional electronic unpacking of packed bags using 3D CT images," presented at the SPIE Electronic Imaging Conference, San Jose, California, January 20, 2009.
- [62] Crawford, C. R., "Development, testing and deployment of distributed and orthogonal threat detection equipment," presented at the Fourth Annual DHS University Network Summit, sponsored by, U.S. Department of Homeland Security, Science and Technology Directorate, Office of University Programs, Washington, District of Columbia, March 12, 2010.

## **ACADEMIC HISTORY**

### **NORTHEASTERN UNIVERSITY, Boston, Massachusetts September 2007 - Present**

As an adjunct professor, collaborated with the Department of Electrical and Computer Engineering on medical imaging and threat detection.

### **TEMPLE UNIVERSITY, Philadelphia, Pennsylvania January 1996 - April 1998**

As an adjunct professor, collaborated with the Department of Diagnostic Imaging on the clinical and technical aspects of CT and MRI. The following is a summary of primary activities.

- Investigated artifacts in CT and MR images and their diagnostic pitfalls in neuroimaging.

### **UNIVERSITY OF WASHINGTON, Seattle, Washington May 1989 - April 1998**

As an adjunct professor, collaborated with the Department of Radiology on clinical aspects of CT. The following is a summary of primary activities.

- Developed new scanning protocols and correction algorithms to minimize the effects of patient motion. The protocols were adopted with the advent of helical scanning and sub-second scanners.
- Supervised one doctorate student's work on the reduction of motion artifacts in CT.

### **MEDICAL COLLEGE OF WISCONSIN, Milwaukee, WI July 1990 - January 1996**

As an adjunct professor, collaborated with the Departments of Radiology and Biophysics. The following is a summary of primary areas of collaboration.

- Organized a journal club for MRI, which identified new technology for GE Medical Systems.
- Served on the academic steering committee.

### **PURDUE UNIVERSITY, West Lafayette, Indiana August 1976 - October 1981**

Did research in the Ultrasonics Information Processing Laboratory under the direction of Professor Avinash C. Kak. The following is a summary of key research accomplishments.

- Wrote thesis: Multipath artifacts in ultrasonic transmission tomography
- Designed, constructed, and programmed a multi-processor ultrasonic transmission tomographic scanner and investigated the sources of image degradation in ultrasonic tomography.
- Developed methods to reduce the influence of multipath artifacts in ultrasound tomography, which made attenuation images equivalent to time-of-flight images.
- Wrote a graphics package for a network of minicomputers running the UNIX operating system, which allowed interactive development of signal processing algorithms.
- Taught courses in Finite State Theory and in Digital Signal Processing.
- Wrote a C cross-compiler to support the development of code for the ultrasound scanner.
- Investigated the use of number theoretical transforms for filtering tomographic data, which led to faster filtration operations.

## **ACADEMIC HISTORY** (continued)

### **OHIO NUCLEAR, Cleveland, Ohio**

**May 1979 - July 1980**

Employed as a consultant while working on graduate studies at Purdue University. The following is a summary of the consulting.

- Developed reconstruction algorithms for a translate-continuous-rotate tomographic scanner, to reduce the scan times of second generation CT scanners.

### **G. D. SEARLE, Chicago, Illinois**

**January 1976 - December 1977**

Employed as a consultant while working on graduate studies at Purdue University. The following is a summary of the consulting.

- Researched the influence of detector and source sampling in CT reconstruction algorithms and showed that aliasing was the source of streak artifacts.
- Showed how to overcome filter aliasing, which allowed for quantitative CT.

### **HUGHES AIRCRAFT, Los Angeles, California**

**May 1976 - August 1976**

Worked as a summer employee prior to beginning graduate studies at Purdue University. The following is a summary of major accomplishments.

- Designed error detection hardware and the monitor interface card for the programmable signal processor used in the F-18 radar.

### **IBM, Rochester, Minnesota**

**June 1975 - August 1975**

Worked as a summer employee while working towards a B.S. at Purdue University. The following is a summary of major accomplishments.

- Wrote software to create and edit data bases used to support automated circuit board assembly equipment, which obviated manual manipulation of the data bases on key punches.
- Wrote step-and-repeat software for numerical controlled drill machines, which automated the development of new manufacturing setups.

## **MASTERS THESIS SUPERVISION**

- [1] Weinstein, Ira D., "Algorithms for the Display of Surfaces in Three Dimensional Medical Computerized Tomography Data," Master of Science, Department of Electrical Engineering, Marquette University, Milwaukee, Wisconsin, May, 1986.
- [2] Santos, Enrique, "Implementation of three-dimensional display algorithms for the display of three-dimensional computerized tomographic images on a large minicomputer," Master of Science, Department of Electrical Engineering, Marquette University, Milwaukee, Wisconsin, July, 1986.
- [3] Kohli, James F., "On the estimation of magnetic resonance spectra using various methods," Master of Science, Department of Electrical Engineering, Marquette University, Milwaukee, Wisconsin, May, 1990.

## DOCTORATE THESIS SUPERVISION

- [1] Ritchie, Cameron J., "Methods for reducing motion artifacts in computed tomography scans of the chest," Doctor of Philosophy, Department of Bioengineering, University of Washington, Seattle, Washington, September, 1993.

## FUNDING

Project Number	Cooperative Agreement, 06-G-020
Source	Transportation Security Administration, Department of Homeland Security
Principal Investigators	Carl R. Crawford and Zhengrong Ying
Title of Project	Evaluation of Screener Performance with 3D Display Systems for Security Technologies
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