MEDICAL APPLICATIONS OF IR FOCAL PLANE ARRAYS

15 March 1998

NICHOLAS A. DIAKIDES
Advanced Concepts Analysis, Inc.
6353 Crosswoods Drive
Falls Church, VA 22044-1209

FINAL PROGRESS REPORT
CONTRACT NO. DAAH04-94-C-0020

Approved for public release; distribution unlimited.

Prepared for

ARMY RESEARCH OFFICE
RESEARCH TRIANGLE PARK, NC 27709-2211

MEDICAL APPLICATIONS OF IR FOCAL PLANE ARRAYS

FINAL PROGRESS REPORT

15 March 1998

Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

under

Contract No. DAAH04-94-C-0020

by

Nicholas A. Diakides

Advanced Concepts Analysis, Inc.
6353 Crosswoods Drive
Falls Church, VA 22044-1209

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
15 March 1998

3. REPORT TYPE AND DATES COVERED
Final Progress Report

4. TITLE AND SUBTITLE
Medical Applications of IR Focal Plane Arrays

5. FUNDING NUMBERS
DAAH04-94-C-0020

6. AUTHOR(S)
Nicholas A. Diakides

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)
Advanced Concepts Analysis, Inc.
6353 Crosswoods Drive
Falls Church, VA 22044-1209

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
ARO 32870.1-EL-S

11. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12 b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This is the final report for Contract DAAH04-94-C-0020 entitled "Medical Applications OF IR Focal Plane Arrays". It was initiated in 1994 as a three year project with funding from DARPA and DDR&E and monitored by ARO. The motivation for this effort was to transfer the highly developed advanced DOD infrared technology to the field of medicine, with a view to achieving a low cost, non-invasive, non-ionizing and effective imaging modality. As such, it could be used on its own or as an adjunct to other imaging methods presently available in order to enhance the overall performance. The major results of this work were the following:(1) established the status of medical IR imaging worldwide and highlighted results of this survey; (2) identified ten major areas of IR imaging uses in medicine through in-depth literature review, contacts, visits, and special workshops; (3) analyzed and defined performance requirements in terms of thermal sensitivity and spatial resolution for several critical medical applications; (4) specified systems requirements for medical IR cameras, both cooled and uncooled types; (5) facilitated the collaborative efforts of researchers by creating a forum for presentations, discussions and workshops on medical infrared imaging; (6) all the above spurred collaborative efforts, teaming arrangements, new initiatives in clinical research; (7) initiated efforts to start clinical research for the quantification of data for the purpose of establishing infrared imaging as an imaging modality in medicine.

14. SUBJECT TERMS
Thermal, Infrared, Imaging, Systems, Medical, Applications, Requirements, Specifications, Performance

15. NUMBER IF PAGES
69

16. PRICE CODE

17. SECURITY CLASSIFICATION OR REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

APPENDIX A — Commercial Activities in IR Imaging Medical Systems: (1) GE Thermal Coronary Angiography System; (2) News Release by Computerized Thermal Imaging (CTI), Inc.

APPENDIX B — International Trip Reports
- (1) United Kingdom
- (2) Japan
- (3) Austria

APPENDIX C — Paper Reprint Published in the European Journal of Thermology

APPENDIX D — Abstracts of Papers in Medical IR Imaging from Proceedings of the IEEE/EMBS International Conferences (1994-1997)

FOREWORD

Background: This is the final report for Contract DAAH04-94-C-0020 entitled "Medical Applications of IR Focal Plane Arrays". It was initiated in 1994 as a three year project with funding from DARPA and DDR&E and monitored by ARO. The motivation for this effort was to transfer the highly developed advanced DOD infrared technology to the field of medicine, with a view to achieving a low cost, non-invasive, non-ionizing and effective imaging modality. As such, it could be used on its own or as an adjunct to other imaging methods presently available in order to enhance the overall performance.

Infrared imaging was limitedly used both in the U.S. and abroad since the mid 1960s to measure the physiology of hemodynamics and of the autonomic nervous system by means of a precise temperature measurement. Unlike imaging techniques such as X-Ray and CT that primarily provide information on anatomical structures, IR imaging provides physiological information not easily measured by other methods. It is utterly non-invasive, as it passively monitors radiant heat emitted by the human body. Hence, it is absolutely risk free unlike X-Rays or even MRI and Ultrasound at a fraction of their cost.

The United States pioneered the clinical use of infrared imaging in the late 1960s in neurology, surgery, oncology, dentistry, and dermatology. It became very popular at the start, but was conducted with inadequate equipment, with little awareness of the scope and limitations of infrared technology, and with little understanding of the underlying physiological and pathophysiological manifestations it can measure. This was a typical example of a premature use of a technology in medicine and thus it was discredited by the majority of the medical community. However, the true believers in this technology continued their efforts in this important research and today we have significant findings which support this revitalized effort, that has been strengthened by the currently available superior infrared technology.

Primary Anticipated Results: The premise of this program was to initially perform an in-depth world-wide review of the status of infrared imaging in medicine, in order to use it as a platform upon which to base its reintroduction and revitalization with state-of-the-art technology. Important factors were to identify current and potential uses of IR imaging in medicine, and to define performance requirements and system specifications. In the process of doing this, it was anticipated that a network of physicians, academicians, biomedical engineers and manufacturers could be formed in order to facilitate collaborative studies and exchange of information and methods. Furthermore, it was deemed necessary to assess IR imaging benefits in terms of cost savings, ease of diagnosis, and improvement of early detection of disease as compared to other diagnostic imaging systems. Another anticipated result was to initiate preliminary studies at leading academic centers in order to stimulate interest for establishing programs to obtain quantification of IR imaging data and develop plans for long term clinical investigations.

Current Status: Substantial progress has been made in the determining of the benefits of IR imaging in medicine in the last three and a half years. This has been reported in current literature, scientific conferences, and workshops. The latest advances in IR focal plane arrays have led to superior performance cameras with the increased sensitivity and specificity required by medical users in both military and non-military medicine. Under the current ARO effort, there has also been marked progress in identifying potential applications for the cost effective use of infrared imaging in medical screening, diagnosis, and therapy.

Several major areas of use were identified through in-depth review of recent literature, contact with leading medical centers, clinicians, and universities. Current and potential uses of IR imaging in medicine are in the areas of neurology, vascular disorders, arthritis and rheumatism, pain (management and control), surgery, neonatology, oncology, tissue viability, emergency medicine, dermatology, ophthalmology, and dentistry.

The impact of the above findings and developments form the basis for the continued exploitation of infrared imaging in medicine and establish its potential value to the medical field. It further enhances the renewed interest in this modality, which provides a non-invasive, non-ionizing, diagnostic and therapeutic form of imaging at very reasonable cost. It has already generated new initiatives in DOD, industry, and universities.

New initiatives using infrared imaging have been initiated in several medical centers (Walter Reed Army Institute of Research, National Institutes of Health, Johns Hopkins University Medical Center, Duke Medical Center, North Carolina State University, Ville Marie Breast Center, Elliott Mastology Centers). These are promising preliminary clinical assessments, and the quantification of these studies have to be continued.

Results from IR systems performance assessments indicate that the present IR technology, both cooled and uncooled, have sufficient sensitivity and resolution for practically all medical imaging applications. However, image processing needs to be enhanced with advanced algorithms which will provide improved image interpretation for the physicians. Further, software packages must be designed to be "user friendly".

Technology Transferred: Through this work, infrared imaging in medicine was exposed to ever-growing audiences. For the first time, the work of the last two decades in this field was given a wider and more unified focus. By means of special tracks and workshops in international conferences organized by the Principal Investigator, this work sparked a significant and ever-growing interest in the capabilities of this modality. For example, from 1994 to 1997 the papers presented at these conferences increased from 6 to 36; many academic and DOD medical centers initiated clinical investigations using infrared imaging. Manufacturers of IR cameras were appraised of this development. This triggered an interest in taking another look at the potential medical market.

1. PROBLEM DESCRIPTION

Infrared imaging in medicine was discontinued as a mainstream modality in the United States in the 1970s, after a very enthusiastic beginning in the 1960s. For example, as early as 1973 IR imaging was included in research studies on breast cancer conducted by the National Cancer Institute at NIH. At that time, they proved inconclusive and eventually were dropped from the testing. However, some of those researchers who continued the work have since published promising results in breast cancer and stated that the failure of the original tests was due to inadequate training in thermography and physiology of the researchers. Furthermore, it was conducted with inadequate equipment, with little awareness of the scope and limitations of infrared technology, and with poor understanding of the underlying physiological and pathophysiological manifestations it can measure. This was a typical example of a premature use of a technology in medicine which resulted in it being discredited by the majority of the medical community. However, the true believers in this technology continued their efforts in this important research, and today we have significant findings which support this revitalized effort that has been further strengthened by the currently available superior infrared technology.

The present program was based on the premise that by:

(1) performing an in-depth review for ascertaining the available current research findings worldwide, it would be possible to identify the most promising areas of applications.

(2) comparing this imaging technique with other available ones, one could establish impact in cost savings, early detection of disease, diagnostic screening effectiveness, and benefits.

(3) defining the image performance requirements and systems specifications needed in a clinical measurement setting, it would be possible to determine factors such as thermal sensitivity, special resolution, SNR, optics, frame rate and image processing.

(4) using the forum of conferences, workshops, briefings, and networking, it would allow the groundwork to be set for collaborative efforts between medical centers, academia, biomedical engineers, and manufacturers.

2. SUMMARY OF MOST IMPORTANT RESULTS

This was a three year contract, and the following are the most significant results:

2.1. Status of Medical IR Imaging Worldwide: An in-depth survey of the status of clinical IR imaging in U.S., Europe, Japan, and Korea was undertaken. The results are highlighted as follows:

(1) United States: The U.S.pioneered the clinical use of IR imaging in the late 1960s and was the first to use it in neurology, surgery, oncology, dentistry, ophthalmology, and dermatology. Presently, its use has been limited due to the following reasons:

(a) early clinical research was conducted with inadequate equipment, with lacking technology and standardization, and with inexperienced users. This led to unreliable results,

(b) strong political bias due to competing technologies.

All the foregoing reasons resulted in the withdrawal of support from both government (Medicare) and insurance companies. Most American manufacturers currently do not use the available technology, because the demand has been curbed by the lack of reimbursement to the patient. However, there is recent increased interest in IR clinical testing by several well-known medical institutions (Harvard, Johns Hopkins, Texas Children's' Hospital, NIH, Thomas Jefferson Medical School, North Carolina State University. etc.). DARPA and the ARMY (MRMC, NVESD) are initiating efforts for clinical studies related to battlefield use. More recently, the exposure gained by the presentations at the IEEE conferences, beginning in 1994 in Baltimore, and the collaborative efforts forged at these, has instigated a forward trend and interest in the involvement and investigation of this modality. For example, in the first conference we had only six papers; in the fourth conference in Chicago we had 36 papers (six sessions of which three were clinical) on this subject.

The American Academy of Thermology is now working on standardization of infrared systems, image processing, training, etc., and these efforts are being coordinated with the Europeans and Japanese in order to develop an international standard.

There has also been some concrete commercial activity as follows:

• General Electric has developed an infrared camera "Thermal Coronary Angiography System" for use in open heart surgery, and is presently marketing it.

• Computerized Thermal Imaging (CTI), Inc., from Lake Oswego, Oregon, has formed a teaming arrangement with TRW to develop and market infrared cameras to be used in medicine. Howard University Hospital in Washington, D.C. is currently doing clinical pre-testing. Some of these tests include breast cancer studies.

More specific information of the above activities is contained in Appendix A.

(2) Europe: The European Association of Thermology established protocols for the use of infrared imaging in selective areas such as rheumatology. clinical pharmacology, Reynaud's phenomenon, etc. Emphasis is placed on quantitative imaging for disease management. A number of academic medical centers support these activities. The British Medical Association listed test procedures with recommended changes for adoption. The European Union developed draft specifications for clinical IR imaging equipment and methodology for standardization within the European Community. This will be submitted to other countries such as U.S., Japan, Korea, etc., for coordination and adoption. The relevant draft was discussed and coordinated at a special workshop (requested by the Principal Investigator) at the Vienna conference of the European Society of Thermology in May 1997.

(3) Japan: Japan is the world's most frequent user of IR imaging in clinical settings (more than 1200 hospitals routinely perform such tests which are readily reimbursed by the Japanese National Healthcare Insurance). Present cost of thermographic test is $50.00, with a projection to reduce it further. The Japanese Industrial Standards Organization sets guidelines for: thermographic testing, standardization for thermographic images, and standardization of image handling and data bases. The Research Center for Advanced Science & Technology, University of Tokyo, sets national specifications for clinical infrared equipment. (More detailed information is included in Appendix B).

(4) Korea: In Korea infrared imaging was introduced in clinical settings only five years ago, but today it is used by more than 300 hospitals for routine screening, diagnostic, and therapeutic testing for both Western and Oriental medicine. Government and insurance companies reimburse all thermographic testing. The infrared equipment is imported primarily from the U.S. and Europe.

2.2. Primary Medical Applications for IR: Ten major areas of use were identified through in-depth review of recent literature, contact with leading medical centers, clinicians, and universities. The specific areas of IR imaging uses are: neurology, vascular disorders, arthritis and rheumatism, pain management and control, tissue viability, oncological and breast cancer, dermatological disorders, surgery, neo-natal, and ophthalmology. It has been ascertained that the clinical areas most likely to lead in medical infrared imaging are as follows:

- Open-heart, organ transplant, and reconstructive surgery.
- Staging and management of diabetes mellitus and liver disease.
- Neo-natal care and early diagnosis of neurological and metabolic disorders.
- Screening of breast and skin cancer.
- Soft tissue and skin injury.

The significant benefits of infrared imaging to the above applications is its ability to detect and characterize pathophysiological abnormalities (e.g. functional imaging) not readily identified by other means, such as X-Rays, CAT, and Ultrasonic imaging, which provide only structural information.

The latest enhancements in MRI systems do provide capability for both structural and functional imaging, but at a far higher cost. Some advantages of IR imaging, as well as some shortcomings, are listed in Table 1.

The impact of the above findings is the basis for the exploitation of infrared imaging in medicine and establishes its potential value to the medical field by the possibility of generating new interest in non-invasive, diagnostic imaging at very reasonable cost. It has already sparked new initiatives in DOD, industry, and universities (for more detailed discussion, see Technology Transfer Section).

2.3. Performance Requirements Analysis: This effort established qualitatively the performance requirements in terms of both spatial resolution and thermal sensitivity for several critical medical applications, which led to the formulation of the IR camera system design specifications which are shown in Figure 1 and Table 2. This is a unique achievement since it has never been done before. Now, it requires further work in order to quantify these data. Additional findings demonstrate that current low cost,uncooled and high resolution scanning IR systems are effective, and are suitable for meeting the performance needs required for most of the clinical uses. This information is of utmost importance to IR system manufacturers and clinicians.

2.4. Performance Analysis of IR Imaging Systems: Modelling results were obtained on the performance of the infrared systems (cooled and uncooled) as a function of aperture and recognition range. Performance curves for present systems and projected future systems were obtained which indicate that uncooled IR systems have the potential to approach the performance of cooled systems with improvements in uncooled materials, thermal isolation structures, and read-out electronics. Additional modelling on medical infrared sensors was performed to obtain thermal sensitivity versus optical aperture at short range as required in a clinical setting. Performance data are shown in Figure 2. This is an accomplishment, since it is the first time that the latter was successfully tried on a medical sensor (see attached results).

The significant benefit of this accomplishment is that it demonstrates both cooled and uncooled infrared systems can be used equally well for certain applications in medicine.

2.5. Comparative Analysis between U.S. and Japanese Medical IR Systems: Japan for some time now has successfully used IR imaging in medicine on a large scale. One third of their hospitals, about 1,200 institutions, use these systems on a regular basis. The Japanese believe that the next step would be to develop a system suitable both in price and operation for use in their outpatient clinics, which outnumber their hospitals, (about 10,000). Hence, it seemed cogent to obtain first-hand information on lessons learned from their wide exposure, and to compare the available systems for this purpose in Japan and the U.S. The factors considered for this purpose were the following: technology, equipment, specifications/standards, number of hospitals, insurance company and government reimbursement of tests. The results show that, although the U.S.

is far superior in IR technology, Japan has better designed systems specifically for medical use, and especially user-friendly. They also lead significantly in other factors as shown in Table 3.

These data are important as a basis for the possible enhancement of the use of this technology in the U.S. For example, we have to address deficiencies like standards, hospital use, insurance companies and government reimbursement, in order to establish it here. Effort was focused on these issues, in addition to initiating further clinical studies at medical centers for validation, but a lot more work is needed.

2.6.Duke University IR Clinical Test: Met with the Chancellor Emeritus, Dr. William Anlyan, and the Chairman of the Department of Radiology, Dr. Carl Ravin, of Duke University Medical Center in order to introduce to them the potential advantages of using IR imaging clinically. The main purpose was to convince them to carry out some basic clinical research on the early detection of breast cancer using this modality. Originally, they were hesitant due to the past history of Thermography, but they were more amenable when we suggested that we could arrange for them to borrow a state-of-the-art camera from the Jet Propulsion Laboratory for preliminary tests. Another key factor in influencing their decision was the viewing of the images taken at the Browman Gray School of Medicine, North Carolina, by Professor Wesley Snyder, North Carolina State University, Mike Grenn, CECOM/NVESD, and Tim White, Lockheed Martin, of the trauma patients as they came into the hospital. [This collaborative team and idea was an off-shoot of the IEEE/EMBS International Conference in Amsterdam, 1996]. The arrangements for Duke were finalized in 1997 and the clinical testing will be in February/March 1998.

This is a significant accomplishment because it is very crucial to have the opportunity to validate the value of IR imaging at a top medical center.

2.7. Assessment of Medical IR Imaging Systems Currently in Use: A survey was made to ascertain what systems were used to produce the clinical data presented at the IEEE/EMBS conference in Chicago.. The questionnaire given to the presenters covered all key characteristics and specifications, including performance such as spatial and thermal resolution, frame rates, size, weight, etc. The rationale for this survey was to correlate the system performance with the quality of the results presented by the speakers.

The significance of this would be to get a comparison of systems and their efficacy in clinical settings. These data were given to Mike Grenn, NVESD, who will do a quantitative performance analysis using the night vision IR model. This will be of great importance for manufacturers to enhance the system performance, and for the users of medical IR cameras to optimize their clinical results.

2.8. Latest Results on IR Imaging in Breast Cancer: A study was conducted to compile the latest findings concerning the use of infrared imaging in breast cancer. The following are some of the most significant results reported:

(1) Dr. Keyserlingk, et al, from Canada recently reported that when mammography is used with infrared imaging, there is an enhancement in sensitivity from 81% to 95%. In addition, in a sampling of 62 breast cancer patients, infrared imaging was especially useful in younger patients. In these clinical studies, infrared was used as an adjuvant imaging modality to mammography ("Infrared Imaging of the Breast: A Preliminary Reappraisal Using Resolution Digital Technology in 62 Successive Cases of Breast Cancer", Proc. Amer. Society of Clinical Oncology, Denver, Colorado, May 1997).

In his recent report "Infrared Imaging of the Breast: A Preliminary Reappraisal Using High Resolution Digital Technology in Addition to Mammography in the Detection of Stage I and II Breast Cancer", Proc. of Workshop on Organized Breast Cancer Programs, Ottawa, Canada, April 1997. Dr. Keyserlingk extends his observations to one hundred patients, 17 were undetected by IR imaging, 16 were undetected by mammography, and only 5 were undetected when both modalities were used together.

(2) Dr.Head et al compared a first generation infrared imager with a second generation (focal plane array), and he reported an enhancement in sensitivity for detection of breast cancer from 32.7% to 50.5%. This work was funded by the U.S. Army CECOM, Night Vision & Electronic Sensors Directorate under a Small Business Innovative Research (SBIR) Program ("Breast Cancer Risk Assessment with an Advanced Infrared Imaging System", Proc. Amer. Society of Clinical Oncology, Denver, Colorado, May 1997).

In a previous paper "Application of Second Generation Infrared Imaging with Computerized Image Analysis to Breast Cancer Risk Assessment, Proc. IEEE/Engineering in Medicine and Biology Society International Conference, Amsterdam, 1996, Dr. Head reported that the second generation infrared imager has greater thermal sensitivity and greater dynamic range which results in a greater ability to demonstrate asymmetric heat patterns which indicates early breast cancer problems.

(3) Dr. Gamagami in his recent book "Atlas of Mammography" (November 1996) reports that with telethermography preneoplastic angiogenic alterations can be seen in asymptomatic patients years before clinical or mammographic manifestations appear. Further, he reports that this modality can be very useful in evaluating the efficacy of chemotherapy before and after treatment of inflammatory carcinoma. In addition, he reports that infrared imaging should be used in conjunction with mammography ("Atlas of Mammography", Blackwell Science, Inc., Nov. 1996). This work has been described in his most recent paper "Infrared Imaging in Breast Cancer, Proc. 19th International IEEE/EMBS Conference, 677-680, 1997.

(4) Dr. Ohashi of the Cancer Institute Hospital, Tokyo, Japan, has demonstrated a significant enhancement of detection of breast cancer by sequential image subtraction during cooling off of the breast, first reports in "On the Diagnosis of Synchronous Bilateral Breast Cancer by Thermography", Biomedical Thermology 15:142-149, 1995, and further elaborated in "Some Considerations on the Diagnosis of Breast Cancer by Thermography in Patients with Non-Palpable Breast Cancer", Proc. 19th International IEEE/EMBS Conference, 670-672, 1997.

(5) Dr. Anbar proposes in his book "Quantitative Dynamic Telethermometry in Medical Diagnosis and Management" (1994).that breast cancer is associated with extravascular production of nitric oxide, which causes vasodilation, manifested as local cutaneous hyperthermia. Hence, infrared imaging can be used to detect this at an early stage of breast cancer malignancy. Dr. Anbar's later publications on the subject are "Hyperthermia of the Cancerous Breast - Analysis of Mechanism", Cancer Letters 84:23-29, 1994, "Thermological Implications of Vasodilation Mediated by Nitric Oxide", European J Thermology (Thermologie Oesterreich) 5:15-27, 1995, "Mechanism of Hyperthermia of the Cancerous Breast", Biomedical Thermology, 15:135-139, 1995, and "The Role of Nitric Oxide as a Synchronizing Chemical Messenger in the Hyperperfusion of the Cancerous Breast", in The Biology of Nitric Oxide Part 5, S. Moncada et al (Eds.) Portland Press, London, 1996, 288a-288d.

2.9. IEEE/EMBS Magazine Special Issues on "Infrared Imaging: An Emerging Technology in Medicine": As a result of this contractual effort, during the last three and a half years there has been a cohesive international focus to consolidate knowledge, experience, clinical data, ideas of standardization and training, and to start collaborative initiatives for reestablishing the basis for the use of infrared imaging in medicine. For this reason, medical infrared imaging was introduced as an emerging technologies topic at the International IEEE/EMBS 1994 Conference in Baltimore. Since then, this effort has continued every year with ever increasing presenters and audiences. In 1997 in Chicago, there were thirty six papers on different aspects of medical applications, and there were two special workshops; one was exclusively on early detection of breast cancer. Given this evolution, the Principal Investigator was invited to be the guest editor for a series of three special issues of the EMBS Magazine dedicated to infrared imaging in medicine. The first issue is focused primarily on introductory and overview papers; the second and third issues will be exclusively on quantitative clinical results and methods, including system requirements and "smart" image processing.

The first issue contains eight articles which were contributed by internationally known experts in the use of infrared imaging in medicine, IR technology, and systems. Francis Ring (UK) presents a paper which traces the development of temperature measurement based on his experience of thermal imaging used in his work in rheumatology and pharmacology. Michael Anbar (USA) reviews the state-of-the art clinical infrared imaging in the last five years (1993-1997) and covers recent developments in clinical thermology in many fields of medicine, ranging from general surgery to ophthalmology. Anbar emphasizes the importance of understanding the mechanisms of physiological dysfunctions that are manifested in dynamic thermal abnormalities. Iwao Fujimasa (Japan) describes novel pathophysiological expressions of infrared images and proposes methods of analyzing procedures of thermal images. Richard Harding (UK) presents his extensive work in the use of infrared imaging in deep venous thrombosis, coming up with definitive conclusions. Kunihiko Mabuchi (Japan) describes the development of an image processing program capable of producing images of the temperature difference between the affected side and the corresponding contralateral healthy side of the body, demonstrating its diagnostic value in a clinical setting. Maurice Bales (USA) presents several clinical examples of soft tissue injury and breast cancer detection where the use of appropriate image processing algorithms substantially enhanced the diagnostic acumen of infrared imaging. Timothy White, et al, (USA) discusses the latest technology of uncooled, low cost infrared imaging, which is of special interest to the medical users..Finally, Brian Harrison, et al, (Japan) reviews the status of medical infrared imaging in Japan.

2.10. Technology Transfer: The following are the new initiatives in technology transfer attributed to this effort:

(1) Quantification of Mustard Injury to Skin Using IR Imaging: This is a new initiative study that has been initiated at Walter Reed Army Institute of Research and will investigate the mustard gas effects on skin and will quantify antidote optimization (principal investigator: Dr. K. Zamani).

(2) High Performance Medical Infrared System: An innovative research project initiated in 1995 for the design, development, and demonstration of a medical IR camera using state-of-the-art military IR technology. The sponsor of this work is the CECOM/NVESD, (principal investigator: M. Grenn).

(3) Hyperspectral Infrared Imaging in Medicine: This work is ongoing at the National Institutes of Health (principal investigator: Dr. N. Lewis). The purpose is to use hyperspectral imaging for identification of chemical species in the tissue, (e.g. Brain, breast, etc.). Advanced focal plane arrays were donated to NIH by DARPA (R. Balcerak) for this project.

(4) Investigation of Diabetes Mellitus Using Infrared Imaging: This work is carried out at Southern Illinois University Medical School in collaboration with Dorex, Inc. (Manufacturer of IR camera systems.) The research program started March 1995 and is projected to continue from two to three years (principal investigator: Dr. R. Traycoff, M.D.).

(5) Identification of Chemicals inside Skin Using IR Imaging: This is a second new initiative at Walter Reed Army Institute of Research, in collaboration with the CECOM Night Vision & Electronic Sensors Directorate. This will investigate the effects of chemical warfare agents or toxins on human skin. Principal investigators: Dr. K. Zamani, WRAIR, and M. Grenn, NVESD.

(6) Studies of Brain Edema using NIR Imaging Spectroscopy: This work is being investigated at Johns Hopkins University Medical School (Biomedical Engineering Department). In support of this study, DARPA and NVESD/BMDO will provide focal plane arrays to improve the performance of the existing systems. Principal investigators are: Prof. N. Thakor and L. Johnson.

(7) IR Imaging for Detection of Perfusion in Trauma**:** This is a new joint research program performed at Browman Gray School of Medicine.in collaboration with North Carolina State University. Principal Investigators are: Prof. W. Snyder and Dr. E. Schwartz, M.D. Preliminary imaging clinical data have been obtained successfully.

(8) Testbed for Burn Trauma: Interest was generated at the U.S. Army Institute of Surgical Research to use IR imaging in investigation and therapy of burn injuries. Major Leopoldo C. Cancio, M.D., Fort Sam, Houston Texas, is the principal investigator. He is collaborating with Dr. Zamani at Walter Reed Army Institute of Research and Professor Wesley Snyder, North Carolina State University. Both have research programs in similar areas using infrared.

2.11 Conferences and Workshops: The following activities are attributed to this project:

(1) Chairman and co-Organizer of the "Medical Infrared Imaging at the Medical Dual-Use Technology Symposium", IEEE/EMBS International Conference, Baltimore, November 1994.

(2) Chairman and Organizer of IEEE/EMBS International Conference: "Medical Infrared Imaging & Technology Transfer", Montreal, Canada, September, 1995.

(3) Medical Infrared Imaging Workshop I, Montreal, Canada: The purpose of this was to start a colloquium and exchange of ideas between international and national scientists, academia, and industry, who were present at the conference. It resulted in serious discussions and ideas of collaboration between them. Even more importantly, it further exposed in a direct manner the importance of developing the use of infrared in medicine.

(4) Organizer & Chairman of the "Advances in Digital Infrared Imaging and Technology Transfer Track", 18th Annual International Conference, IEEE/Engineering in Medicine and Biology Society, Amsterdam, The Netherlands, November 1996.

(5) Medical Infrared Imaging Workshop II, Amsterdam, The Netherlands: (Organizer and Chairman) The purpose of this was to expand colloquium and exchange of ideas between international and national scientists, academia, and industry, who were present at the conference. It resulted in serious discussions and ideas of collaboration between them. Even more importantly, it further exposed in a direct manner the importance of developing the use of infrared in medicine. Further, it triggered the development of a unique CD-ROM medical IR imaging database. Principal investigator will be Professor

Colin Roberts, Department of Medical Engineering and Physics, King's College London, UK. This work was sponsored and funded by BMDO, and is in its final stage of producing the CD-ROM with all the history.

(6) Chairman and Organizer of an IR Imaging Workshop: This workshop took place at the Conference for Advanced Technology Applications to Combat Casualty Care (ATACCC-95), Fort Walton Beach, FL, May 1997.

(7) 7th European Congress of Thermology: Invited to participate and give a paper by Professor Raymond Clark, President European Society of Thermology, held in Vienna, Austria, May 1997 (see trip report in Appendix "B").

(8) Organizer & Chairman of the "Infrared and Technology Transfer Imaging Tracks", 19th Annual International Conference, IEEE/Engineering in Medicine and Biology Society, Chicago, November 1997.

(9) Organizer and Chair of Following Two Workshops: 1) Medical Infrared Imaging Workshop III, and 2) IR Imaging in Breast Cancer, at the 19th Annual International Conference, IEEE/Engineering in Medicine and Biology Society, Chicago, November 1997. The purpose of this was to expand colloquium and exchange of ideas between international and national scientists, academia, and industry, who were present at the conference, and to discuss new findings and results of previously formed collaborative initiatives, and to stimulate new ones.

3. LIST OF PUBLICATIONS

3.1. Papers Published in Journals and Proceedings:

1. Diakides, N.A., Jenkins, D.P., "Medical Uses of Infrared Sensors", Proc.of the 1995 National Infrared Information Symposium, Laurel, MD, July 1995

2. Diakides, N.A., Balcerak, R., "Recent Technological Advances in Infrared Imaging", Journal of the Japanese Society of Thermology, Vol. 16, No.1,47-53, May 1996

3. Balcerak, R., Jenkins, D.P., Diakides, N.A,. "Uncooled Infrared Focal Plane Arrays", Proc. of 18th Annual International Conference of IEEE/ Engineering in Medicine and Biology Society, Amsterdam, Netherlands, (Nov. 1996)

4. Diakides, N.A., "New Developments in Low-Cost IR Imaging Systems" European Journal of Thermology (formerly "Thermologie Oesterreich", Vol.7, No. 4, Oct.1997 (see Appendix C).

5. Diakides, N.A., "Advances in Digital Infrared Imaging in Medicine", Proc. of the conference for Advanced Technology Applications to Combat Casualty Care, Fort Walton Beach, FL, May 1997

3.2. Other Related Papers:

The following are additional papers related to this effort, which were solicited by the Principal Investigator for tracks organized and chaired by him at the following conferences. (Supported by grants from ARO International Programs, DARPA, BMDO, and NASA):

1. 16th Annual International Conference of IEEE/Engineering in Medicine and Biology Society (EMBS), Baltimore,MD, November, 1994

2, 17th Annual International Conference of IEEE/EMBS , Montreal, Canada, September, 1995

3. 18th Annual International Conference of IEEE/EMBS Conference in Amsterdam, Netherlands, October, 1996.

4. 19th Annual International Conference of IEEE/EMBS, Chicago, IL, November, 1997

Abstracts of all the "IR Imaging in Medicine" papers from the above conferences are contained in Appendix D.

3.3. Presentations to High Level DOD Officials:

Briefed the Following Key People on Medical Infrared Imaging: 1) General Zajtchuk, Commander, U.S. Army Medical Research and Materiel Command, Fort Detrick, MD (Apr.8, 1997); 2) Dr. Anna Johnson-Winegar, Director, Environmental and Life Sciences, DDR&E, Pentagon, (Aug.20,1997); 3) Dr. David Heberlein, Director, CECOM/NVEOL, Fort Belvoir, VA, (Aug.18,1997) 4) Dr. Stephen Morse, DARPA/DSO, Arlington, VA, (Nov.14, 1997); 5) Dr.Lance Davis, Director, Laboratories & Technology Transfer, DDR&E, Pentagon (Feb.5,1997). The briefing of these key people generated support of this program at high levels.

4. LIST OF PARTICIPATING SCIENTIFIC PERSONNEL

Nicholas A. Diakides, Ph.D., Prinicpal Investigator.

5. BIBLIOGRAPHY

1. Abernathy,M., Abernathy,T.B., "International Bibliography of Medical Thermology", American Academy of Thermology, Washington, D.C., 1987

2. Ammer,K., and Ring,F.J., (editors), "The Thermal Image in Medicine and Biology", Uhlen-Verlag, Vienna, 1995

3. Anbar,M., "Dynamic Area Telethermometry - Part I", Medical Electronics, p 62-73, April 1994

4. Anbar,M., "Dynamic Area Telethermometry - Part II", Medical Electronics, p. 73-85, June 1994

5. Anbar, M., "Quantitative Dynamic Telethermometry in Medical Diagnosis and Management", CRC Press, 1994

6. Anbar, M., "Local Hyperthermia and Local Pain in Joint Inflammation; Two Manifestations of excessive Local Nitric Oxide Production", Proc.of the American Academy of Thermology, PA, April 1997

7. Anbar, M., Grenn,M.W., Marino, M.T., Milescu,L., Zamani, K.,"Fast Dynamic Area Telethermometry (DAT) of the Human Forearm with a GaAs Quantum Well Infrared Focal Plane Array Camera",Thermologie Osterreich , Vol.7, No.3, 105-118, July 1997.

8. Anbar, M., Milesch, L., Grenn, M., Zamani, K., Marino, M., "Study of Skin Hemodynamics with Fast Dynamic Area Telethermometry (DAT)". Proc.19th Annual Intl. Conf. IEEE/EMBS, Chicago, IL, November 1997,

9. Armalic,R., et al, "Prognostic Use of Thermography in Breast Cancer", International Congress of Thermography, August 1992

10. Bacon,P.A., Collins,A.J., Ring,F.J., Cosh,J.A., "Thermography in the Assessment of Inflammatory Arthritis", Clinics in Rheumatic Diseases-Diagnosis and Treatment, Vol.2, p.51-65, 1976

11. Balcerak,R., Jenkins,D.P., Diakides,N.A., "Uncooled Infrared Focal Plane Arrays", Proc. Of the 18th Annual International Conference of the IEEE/EMBS Society, Amsterdam, Netherlands, Nov.1996

12. Braunstein, M., Chan R., Levine, R., "Dye-Enhanced Multispectral Transillumination for Breast Cancer Detection: Feasibilty Measurements", Proc. 19th Annual Intl. Conf. IEEE/EMBS, Chicago, IL, Nov.1997.

13. Braunstein, M., Chan, R., Levine, R., "Simulation of Dye-Enhanced Near-IR Transillumination Imaging of Tumors", Proc. 19th Annual Intl. Conf. IEEE/EMBS, Chicago, IL, Nov.1997.

14. Blechman,B.M., and Lush,S.C., "Dual-Use Applications of Infrared Sensitive Materials, ARPA Report, pp 14-35, June 1993

15. Chang, J., Graber, H., Barbour, R., "An Algorithm that Estimates Background Lumifore for Luminescence Optical Tomography", Proc. 19th Annual Intl. Conf. IEEE/EMBS , Chicago, IL 1997.

16. Clark.R.P., and M.L.de Calcina-Goff, "International Standardization in Medical Thermography - Draft Proposal", Proc.of the 18th Annual International Conference of the IEEE/EMBS Society, Amsterdam, Netherlands, Nov.1996

17. Coffield,P.C., and Gooden,C.E., "Biomedical Application of High-Resolution Infrared and Parallel Processing Technologies", Proc.of the 18th Annual International Conference of the IEEE/EMBS Society, Amsterdam, Netherlands, Nov.1996

18. Diakides, N.A., "Advances in Digital Infrared Imaging in Medicine", Proc. of the Conference for Advanced Technology Application to Combat Casualty Care, Fort Walton Beach, FL, May 1997

19. Diakides, N.A., "New Development in Low-Cost IR Imaging Systems, European Journal of Thermology (formerly Thermologie Oesterreich"), vol. 7, No.4, 213-215, Oct. 1997.

20.. Diakides, N.A., and Balcerak, R., "Recent Technological Advances in Infrared Imaging", Journal of the Japanese Society of Thermology, Vol. 16, No.1, 47-53, May 1996

21. Diakides, N.A., and Jenkins,D.P., "Medical Uses of Infrared Sensors", Proc. of the 1995 National Infrared Information Symposium", Laurel, MD July 1995

22. Dittmar,A., et al, "Measurement of Heat Clearance of Skin Blood Flow of Healthy Burned and Grafted Skin", Prog. Clin. Biol. Res., 107, 413-420, 1982

23. Freeman, J., Marcucci, L., Lewis, E., Blume, B., "Multispectral and Hyperspectral Imaging: Applications for Medical Diagnosis", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il, Nov.1997

24. Fujimasa, I., Chinzei,T., and Mabuchi,K., "Converting Algorithms for Detecting Physiological Function Changes from Time Sequential Thermal Images of Skin Surface", Proc. of 17th Annual International Conference of IEEE/EMBS, Montreal, Canada, Sep.1995

25.. Fujimasa,I., Chinzei,T., and Mabuchi,K., "Development of a Database for Medical Imaging", Proc.of the 18th Annual International Conference of the IEEE/EMBS Society, Amsterdam, Netherlands, Nov.1996

27. Fujimasa, I., Saito, I., Chinzei, T., "Far Infrared Medical Imagae Database on World Wide Web", Proc. 19th Annual Intl. Conf. IEEE/EMBS, Chicago, IL., Nov. 1997.

28. Gamagami,P., "Atlas of Mammography", Blackwell Science, Inc., November 1996

29. Gamagami, P., Silverstein, M., Waisman, J., "Infra-red Imaging in Breast Cancer", Proc. 19Th Annual IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

30. Grenn,M., "Recent Advances in portable Infrared Imaging Systems", Proc.of the 18th Annual International Conference of the IEEE/EMBS Society, Amsterdam, Netherlands, Nov.1996

31. Grenn, M., "Performance of Portable Staring Infrared Cameras", Proc. 19Th Annual Intl. IEEE/EMBS Conf., Cchicago, Il., Nov.1997.

32. Goldberg,G.S., "Infrared Imaging, Magnetic Resonance Imaging Correlated in 35 Cases", Thermology, vol.1,4,207-211, 1986

33. Gunapala, S, Krapbach, T, Bandara, S., Liu, J., "Portable Long-Wavelength Camera for Civilian Applications", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov.1997.

34. Gupta, N., Dahmani, R., "Acousto-Optic Sensing and Imaging for Biomedical Applications", 19th Annual Intl IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

35. Harding,R.J., "Thermal Imaging in the Investigation of Deep Venous Thrombosis", Proc. of 17th Annual International Conference of IEEE/EMBS, Montreal, Canada, Sep.1995

36... Harding,R.J., and Wright,A.M.,"Non-Invasive Imaging in the Investigation of Deep Vein Thrombosis in Pregnancy",Proc.of the 18th Annual International Conference of the IEEE/EMBS Society, Amsterdam, Netherlands, Nov.1996

37. Harding, J., Barnes, K., "Is DVT Excluded by Normal Thermal Imaging - An Outcome Study of 700 Cases", Proc. 19th Annual Intl.IEEE/EMBS Conf., Chicago, IL, Nov. 1997.

38. Harrison, B., Mabuchi, K., "Biomedical Infrared Imaging in Japan: Present Status and Future Strategies", Proc. 19th Annual Intl. IEEE/ EMBS Conf., Chicago, IL., Nov. 1997.

39. Head,J.F., Wang,F., Lipari,C.A., and Elliott,R.L., "Breast Cancer Risk Assessment with an Advanced Infrared Imaging System", Proc. Of the American Society of Clinical Oncology, Denver, CO, May 1997

40.. Head,J.F., Lipari, C.A., Wang, F., Davidson,J.E., and Elliott, R.L., "Application of Second Generation Infrared Imaging with Computerized Image Analysis to Breast Cancer Risk Assessment", Proc.of the 18th Annual International Conference of the IEEE/EMBS Society, Amsterdam, Netherlands, Nov.1996

41. Head, J., Lipari, C., Wang, F., Elliott, R., "Image Analysis of Digitized Infrared Images of the Breast of a First Generation Infrared Imaging System", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

42. Hielscher, A., "Methods in Near-Infrared Photon Migration Tomography", 19th Annual Intl IEEE/EMBS Conf., Chicago, IL, Nov. 1997.

43. Hines, J., Somps, C., Madou, M., "Space Biosensor Systems: Implications for Technology Transfer", 19th Annual Intl. IEEE/EMBS Conf., Chicago, IL., Nov. 1997.

44. Hooshmand, H., "The Role of Infrared Thermography in Diagnosis and Management of Pain", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

45. Johnson,L., Thakor,N., and Hanley,D., "Study of Near Infrared Imaging of a Model of Brain Edema", Proc.of the 18th Annual International Conference of the IEEE/EMBS Society, Amsterdam, Netherlands, Nov.1996

46. Jones, B., Ring, F., "A Database of Archival Infrared Thermal Imaging in Medicine Papers", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

47. Keyserlingk,J.R., Ahlgren, P.,and Yu,E.,"Infrared Imaging of the Breast: A Preliminary Reappraisal Using Ultrasensitive High Resolution Digital Technology in 62 Successive Cases of Breast Cancer", Proc. Of the American Society of Clinical Oncology, Denver, CO, May 1997

48. Keyserlingk, J.. Ahlgren, P., Yu, E., Belliveau, N., "The Contribution of Currently Available High Resolution Infr-Red Imaging to the detection of Stage I and II Breast Cancer", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

49. Kidder, L., Levin, I., Lewis, E., "Infra-red Spectroscopic Imaging Using Focal-Plane Arrays: Applications to Tissue Analysis and Histopathology", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

50. Kim,Y.S., "Correlation of Pain Severity with Thermography", Proc. of 17th Annual International Conference of IEEE/EMBS, Montreal, Canada, Sep.1995

51. Kim,Y.S., and Cho,Y.E., "Pre-and Postoperative Thermographic Imaging on the Lumbar Disc Herniations", Proc. Of the 16th Annual International Conference of IEEE/EMBS, Baltimore, MD, Nov.1994

52. Lawson,W.,Beneliyahu,D., Meinken,L., Chernilas,J., Novotny,H.,Cohn,P., Dervan,J.,"Infrared Thermography in the Detection and Management of Coronary Artery Disease", American Journal of Cardiology, 72:894-896, 1993

53. Lee, S.K., Kim,Y., "Study of the Thermal Differences on the Meridian Points Used to the Cold Hypersensitivity", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

54. Lipari, C., Head, J., "Advanced Infrared Image Processing for Breast Cancer Risk Assessmenst", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

55. Luther, D., Davidson, J., Cromer, R., Head, J., "A Head Mounted Infrared Imager for Treating the Wounded on the Battlefield", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il.,Nov. 1997.

56. Mabuchi,K., Chinzei,T., Nasu,Y.,Genno,H., Fujimasa,I., "Use of Thermal Rhythmography for the Evaluation of the Autonomic Nervous Function", Proc. Of the 16th Annual International Conference of IEEE/EMBS, Baltimore, MD, Nov.1994

57. Mabuchi,K., Chinzei,T., Fujimasa,I., "Thermal Endoscopic systems and their Applications in the Biomedical Field", Proc. of the 16th Annual International Conference of IEEE/EMBS, Baltimore, MD, Nov.1994

58. Mabuchi,K., Chinzei,T., Fujimasa,I., Haenos, S., Abe, Y., Yonezawa, T., "An Image-Processing for the Evaluation of Assymetrical Thermal Distributions", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

59. Maca, T., Schmaldienst, S., Atteneder,M., Fasching, S., Harl, W., Katzenschlager, R., Knespel, E., Koppensteiner, I., Koppensteiner, R., Ugurlouglu, A., Willford, A., Ehrimger, H., "Infrared Thermography for Control of Hemodialysis Shunts", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

60. Marcott, C., Reeder, R., Paschelis, E., Boskey, A., "FT-IR Chemical Imaging of Biomineralized Tissue Using a Mercury-Cadmium-Telluride Focal-Plane Array Detection", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

61. Marshall, C., Breen, T., Kohin.M., Watson, W., Murphy, R., Butler, N., Parker, T., Perich, L., "Quantitative and Imaging Performance of Uncooled Microbolometer Sensors for Medical Applications", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

62. Martinez-Cole, A., Cooper, P., Murphy, G., Nguyen, H., "Assessment of a Laser Powered Multiwavelength Near-Infrared Red Spectrometer", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

63. Nakagawa, E., Minamitani, H., Ochiai, R., Yamamurah, H., "Measurement of Regional Oxidative Metabolism in Muscle Using Near-Infrared Spectrscopy", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

64. Ohashi,Y., et al., "Significance of Dynamic Thermography in the Diagnosis of Breast Cancer", International Congress of Thermography, Aug. 1992

65. Ohashi, Y., Uchida,I., "Some Considerations on the Diagnosis of Breast Cancer by Thermography in Patience with Non-Palpable Breast Cancer", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

66. Pasley, R., Wolf, E., Bade, H., Leffler, C., Daley, M., "Design of Near Infrared Reflectometer", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

67. Ramlau,C., and Sledzikowski,J., "Combination of Thermographic and Ultrasound Methods for Diagnosis of Female breast Cancer", European Journal of Gynaecological Oncology, 14 (Supp):152-154,1993

68. Ring.F.J., "Criteria for Thermal Imaging in Medicine", Proc. of 17th Annual International Conference of IEEE/EMBS, Montreal, Canada, Sep.1995

69. Ring,F.J.,Thomas,D., Ammer,K., Engel,J.M., "Thermal Imaging in Rheumatic and Neuromuscular Disease, EURAL Bulletin, vol.3, p.85-86, 1990

70. Roehrig, H., "Hybrid Detector Technology Applied to Digital Mammography", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

71. Scanlon, M., "Acoustic Sensor Pad for Physiological Monitoring", Proc. 19Th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

72. Snyder,W.E., Wang,C., "Improving the Resolution of Infrared Images of the Breast", Proc.of the 18th Annual International Conference of the IEEE/EMBS Society, Amsterdam, Netherlands, Nov.1996

73. Snyder, W., Schwartz, E., Snyder, G., "Thermal IR Imaging in Trauma", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

74. Such, O., Acker, S., Blazek, V., "Mapped Hemodynamic Data Acquisition by Near Infrared CCD Imaging", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

75. White, T., Eriksen, K., Nicoli, A., "Three-Dimensional Ultrasonic Imaging with a Fully Populated 128X128 Array", Proc. 19th Annual Intl. IEEE/EMBS Conf., Chicago, Il., Nov. 1997.

76. Zamani,K.,.del Grande,N., Bonner,M., Marino,M., "Digital Dual Band Infrared Imaging in Assessment of Nitrogen Mustard Injury in Skin", Proc.of the 18th Annual International Conference of the IEEE/EMBS Society, Amsterdam, Netherlands, Nov.1996

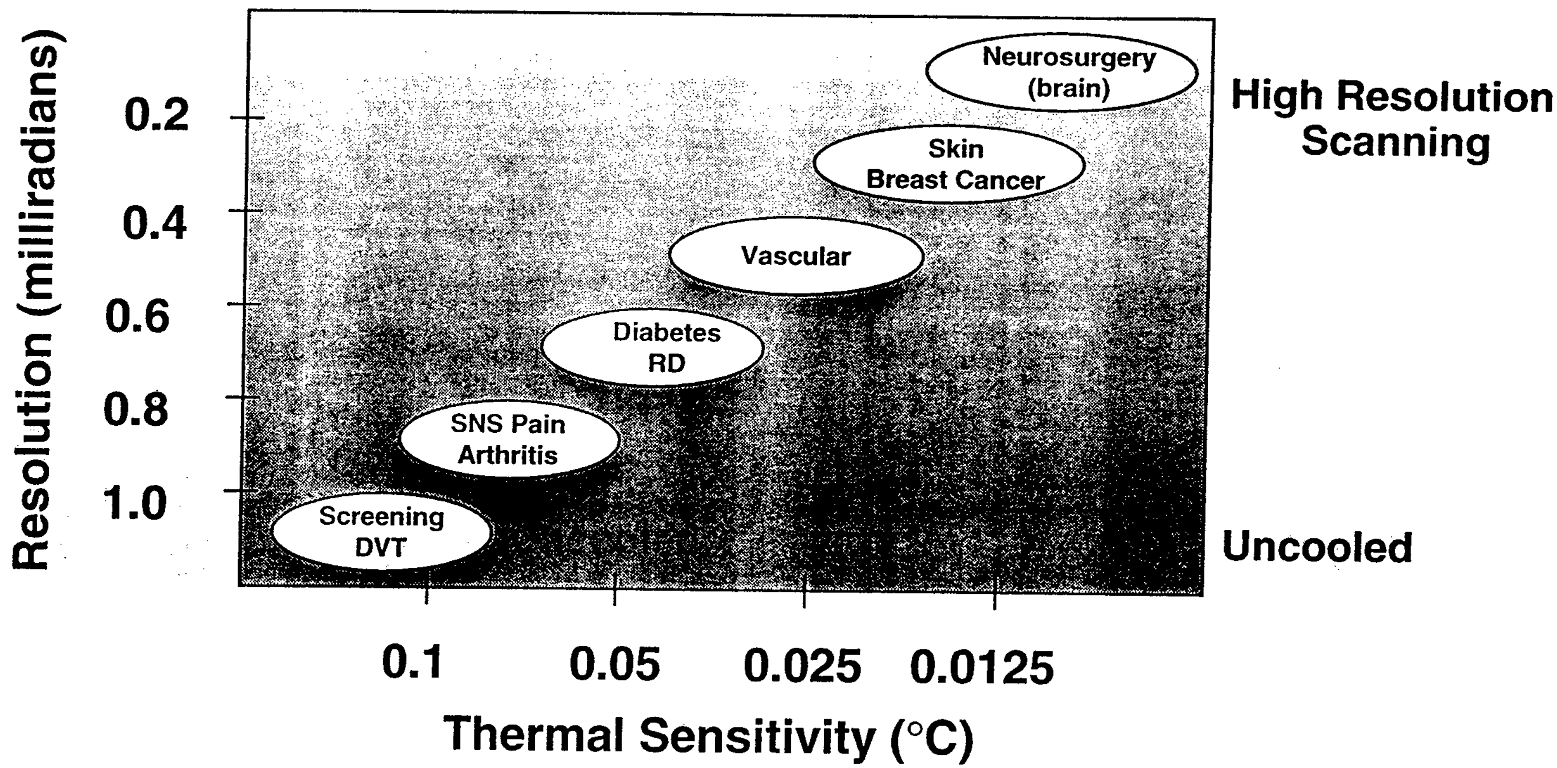


Figure 1 Performance requirements of both thermal sensitivity and spatial resolution for several medical applications

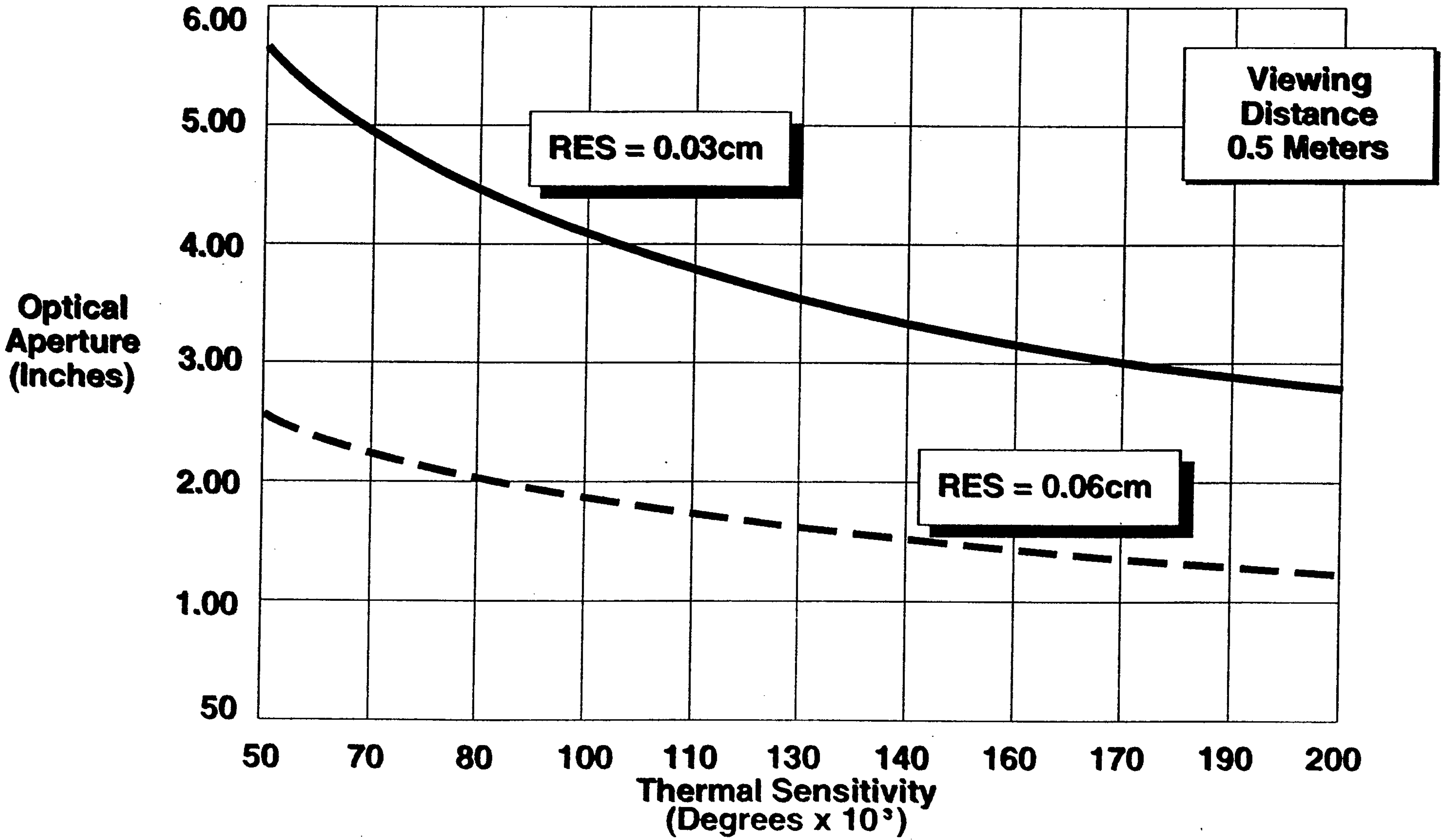


Figure 2 Performance curves of optical aperture versus thermal sensitivity at two different resolution settings for an optimized medical IR camera

TABLE 1

Advantages of Infrared Imaging in Medicine as well as Some Shortcomings

ADVANTAGES	SHORTCOMINGS
◆ Non-invasive	◆ Diagnostic sensitivity
◆ Non-ionizing source	◆ Diagnostic specificity
◆ Inexpensive	◆ Lack of quantitative clinical data
◆ Painless	
◆ Technology already available (from military) ➤ Detector materials ➤ Focal plane arrays ➤ Advanced read-out circuitry ➤ Smart image processing algorithms ➤ Infrared systems	

TABLE 2

IR Camera Design Specifications for Both Cooled and Uncooled Systems

Parameter	High Resolution Scanning	Uncooled
Array Size	≥ 512x512	≥ 256x256
Spectral Band (μm)	3-5 / 8-12*	3-5 / 8-12*
Sensitivity (°C)	0.01	0.1
Resolution (mr)	0.1	1.0
Object Distance (cm)	50	100
Object Size (cm)	10	20
Autofocus	Yes	Yes
Autocalibration	Yes	Yes

* 8 - 12 μm is preferrable wavelength

TABLE 3

Comparison of the Status of Medical IR Imaging Between
Japan and USA

	Japan	U.S.
Technology	○	◍
Equipment	◓	○
Standards	◍	●
# Hospital	◓	●
Insurance	◍	●
Government	◍	●
ARPA Interest	—	◍

◍ best
◓ above average
○ average
◒ below average
● poor

APPENCIX A

Commercial Activities in IR Imaging Medical Systems: (1) GE Thermal Coronary Angiography System; (2) News Release by Computerized Thermal Imaging (CTI), Inc.

IVA 2000

THERMAL CORONARY ANGIOGRAPHY SYSTEM

ON DEMAND INTRAOPERATIVE
IMAGING OF CORONARY VESSELS

GE Medical Systems

A Safe, Simple Method for Evaluating the Success of Myocardial Revascularization

IVA 2000 is the word's first thermal imaging system designed especially for use in Coronary Artery Bypass surgical procedures.

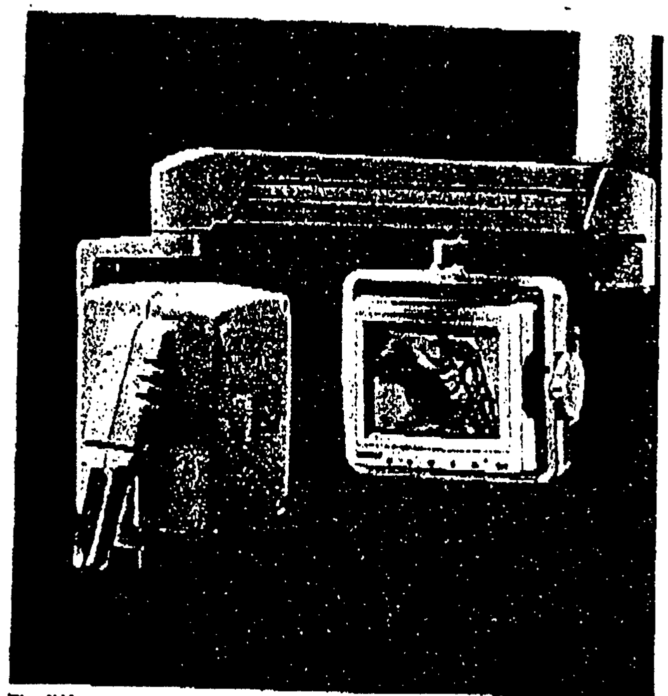
Thermal Coronary Angiography (TCA) can help surgeons immediately identify problems during bypass procedures by providing real-time, non-invasive images of blood flow and perfusion without the use of ionizing radiation or contrast agents.

Clinical Applications

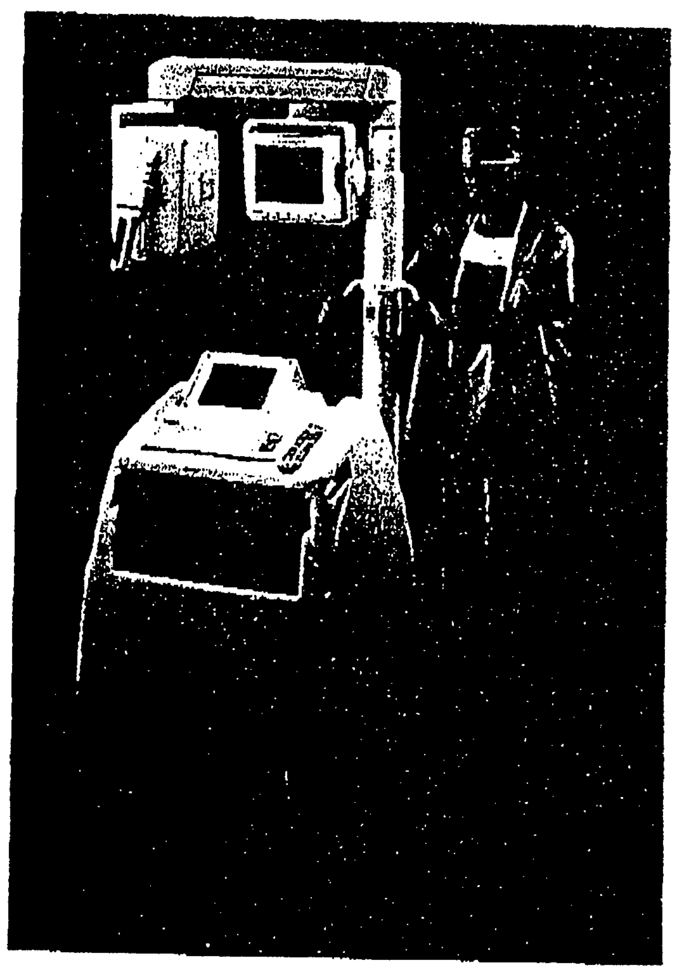
- Verify graft patency in both open heart and minimally invasive IMA procedures
- Verify blood flow and perfusion after revascularization
- Aid in locating native coronary arteries
- Detect cardioplegia perfusion to ensure myocardial protection
- Ensure distal anastomotic quality
- Detect distal occlusions
- Locate intramuscular coronary arteries during re-operation

System Benefits

- Reduced post-operative complications due to graft closure or misplacement of the distal anastomosis
- Non-invasive
- No ionizing radiation or contrast required
- Does not interfere with surgical procedure
- Available in both mobile and ceiling mounted configurations
- Camera can be easily positioned via video image mode
- SVHS recorder and video printer for procedure documentation



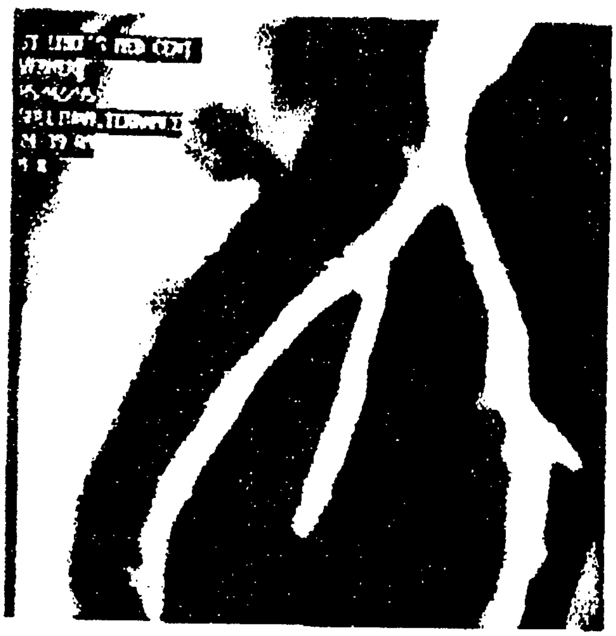
The IVA 2000 is available in both ceiling mounted and mobile configurations.



IVA 2000 Clinical Images

Warm blood: LITA to LAD and Diagonals.

SVG: Warm cardioplegia to the PDA.



Warm blood: S.V.G. to Diagonals.

Thermal Angiogram: Flow of cold cardioplegia for identification of the native coronary arteries.

GE Medical Systems

IVA 2000 COMPONENTS

Easy positioning camera boom

High resolution Thermographic camera on swivel mount

Positionable high resolution video monitor

Boom separates from mobile unit for table side positioning. (Boom hangs from ceiling on ceiling mounted version)

High resolution monitor mounted on base for additional viewing flexibility

Hand held control unit allows system to be operated remotely

SVHS video recorder and thermal printer

Built-in personal computer for automatic operation and clinical programs

GE Medical Systems

Comprehensive Support is Standard Equipment

GE stands behind every IVA 2000 system with a variety of programs and services to help ensure you get the most from your equipment investment.

- GE service support is delivered by one of the industry's largest and best trained service forces
- GE's OnLine Center provides 24 hour service and applications support
- Locally based service personnel help ensure fast response
- On-site applications training
- TiP-TV satellite broadcasts, video conferences and training
- GE offers a wide range of financial packages that can be tailored to meet your specific needs

GE Medical Systems

96-4503

GE Medical Systems – Americas: [illegible]
P.O. Box 414, Milwaukee, Wisc [illegible]
GE Medical Systems – Europe [illegible]
Paris, France
GE Medical Systems – Asia
Tokyo, Japan – Fax 81 3-3223 [illegible]
Singapore – Fax 65-291 7006

CTI
COMPUTERIZED THERMAL IMAGING, INC.™

6105 Macadam
Portland, OR 97201

FOR IMMEDIATE RELEASE: Thursday, June 12, 1997

CONTACT: Tracy Murphy
Computerized Thermal Imaging, Inc.
503-293-4311

Madeleine Franco
Andrew Graft
Jordan Richard Assoc.
801-595-8611

COMPUTERIZED THERMAL IMAGING SUBSIDIARY BEGINS FDA CLINICAL TRIALS, FILES PATENT APPLICATION FOR BREAST IMAGING SYSTEM

LAKE OSWEGO, ORE.—Computerized Thermal Imaging, Inc. (CTI; OTCBB: COII) announced today that its wholly owned subsidiary, Thermal Medical Imaging (TMI) has begun clinical trials of the company's breast imaging system for submission to the FDA.

The first clinical site for the trials is Howard University Hospital (Washington, D.C.), where the system has been in clinical pre-testing since early 1996. Such testing includes a number of breast cancer-related studies, with particular emphasis on African-American women, among whom breast cancer represents the leading cause of death. Two additional sites are scheduled to begin trials using the same protocol later this summer.

The clinical trials have been designed to test the efficiency of TMI's imaging system as an adjunctive technology to mammography and clinical palpation. Specifically, the objective is to test whether the addition of digital thermal information to results of mammography or clinical palpation increases the ability of physicians to differentiate benign from malignant breast abnormalities. The study protocol involves the testing of women whose screening mammogram and/or clinical examination is determined to be abnormal.

In accordance with the study protocol, the women will have an examination using TMI's system prior to undergoing biopsy. Favorable results would then allow TMI to bring to market a breast examination technique that would enable physicians to better classify previously indeterminate screenings, which presently lead to hundreds of thousands of unnecessary surgical procedures each year. Additionally, the trials would serve as a basis for the continued clinical testing of the TMI system as a stand-alone screening device.

Thermal Medical Imaging also announced today it has filed a patent application for the patient-positioning examination table developed as part of its breast imaging system. The examination table, developed and tested in part by TRW Healthcare Information Systems (San Bernadino, Calif.), allows 360-degree views of the breast and adjacent lymph nodes, while the patient rests prone.

TMI's system employs specialized computer algorithms to analyze images of the breast, which facilitate the identification of suspicious regions. The procedure is simple and painless, and it involves no compression. TMI has partnered with TRW over the last year to perfect not only the device's data collection process but also its data analysis algorithms. TRW was selected for the effort based upon its strong reputation and experience with systems integration and imaging technology in the health care market.

- more -

CTI
COMPUTERIZED THERMAL IMAGING, INC.™

6105 Macadam
Portland, OR 97201

FOR IMMEDIATE RELEASE: Thursday, May 29, 1997

CONTACT: Tracy Murphy
Computerized Thermal Imaging, Inc.
503-293-4311

Madeleine Franco
Andrew Graft
Jordan Richard Assoc.
801-595-8611

COMPUTERIZED THERMAL IMAGING, INC. NAMES NEW PRESIDENT, ANNOUNCES RECEIPT OF $1.7 MILLION OF NEWLY INFUSED CAPITAL IN 1997

LAKE OSWEGO, OR—Computerized Thermal Imaging, Inc. (CTI; OTCBB: COII) announced today that it has named David A. Packer, formerly the manager of TRW Engineering Office (Ogden, Utah), as president of the company, effective June 1, 1997.

Packer brings to CTI 22 years of technical and management experience at TRW as a senior systems engineer and engineering manager, with assignments ranging from classified satellite surveillance projects for the U.S. Department of Defense to high-tech design and integration projects for civil government, U.S. business and foreign business contacts. While at TRW, he worked to develop a hospital systems integration program linking several U.S. military bases to telemedicine users in the field. Packer holds a B.S. degree in electronics from Brigham Young University.

Following Packer's appointment as president, Gen. R.V. Secord, former president of CTI, will assume the role of vice chairman while retaining the title of chief operating officer. As COO, Secord is responsible for the coordination of domestic and international contracts for delivery.

According to Secord, the acquisition of Packer's services represents a tremendous step forward for CTI. "We are confident that Dave's experience supervising an impressive number of large and varied high-tech projects for TRW will lead directly to improvements in CTI's drive toward deployment," said Secord.

Packer's first assignment with CTI is to oversee ongoing efforts to improve the reliability and user-friendliness of the CTI thermal imaging system. Additionally, he will oversee all CTI system networking applications. In this regard, his experience as project manager for the installation of the world's largest local area network (LAN) at Hill Air Force Base (Ogden, Utah) has direct application in CTI's plans.

During the first five months of calendar year 1997, CTI has raised nearly $1.7 million for capital contributions and convertible debentures to facilitate the execution of its business plan. Included within these funds are monies needed to put CTI on a fully reporting basis with the Securities and Exchange Commission—the first step in seeking NASDAQ small cap status. "With this funding and the well-timed addition of Dave Packer to our executive core, we look forward to taking important next steps," said Secord.

Computerized Thermal Imaging, Inc. (CTI) is in the business of deploying under a "use agreement" its computerized thermal imaging systems to hospitals, health management organizations and free standing imaging centers worldwide. By monitoring the body's temperature regulatory systems, CTI's technology enables health care providers to discover and observe physiological anomalies in human soft tissue.

###

APPENDIX B

International Trip Reports

ACA Advanced Concepts Analysis, inc.

TRIP REPORT
(UK Oct. 07 - 16, 1994)

To: U.S. Army Research Office
ATTN: Procurement Office (Ms. Terry)
Research Triangle Park, NC

From: Nicholas A. Diakides, Ph.D.
Advanced Concepts Analysis, Inc.
6353 Crosswoods Drive
Falls Church, V 22044

Subject: Thermal Imaging Conference, Bath, UK
Ref: Contract DAAH04-94-C-0020

Date: November 18, 1994

Conferences/Workshops

Attended two consecutive conferences held in Bath, UK (October 11 - 15, 1994). The first dealt with the principles and development of thermal imaging and was organized by the Imaging Science and Technology Group of the Royal Photographic Society. The second was organized by the European Society of Thermology and was focused on medical infrared applications. Delegates from Japan, Korea, Australia and the US, with the majority from European countries (see attached program agenda). In addition to the conferences, several workshops with in-depth discussions took place at which manufacturers, academic researchers and clinical practitioners debated the uses and possible expansion of thermal imaging for non-military purposes. I was invited to participate in these discussions and the standardization workshop. I was actively involved in both and participated in the drafting of a pertinent document, and voted for the adoption of certain standards to establish specification of equipment and methods for clinical measurements. I also co-chaired one of the sessions on Thermal Imaging Applications.

Discussion

This forum provided an ideal opportunity for me to be exposed to and discuss with international experts several central issues related to the use of infrared imaging in medicine (see attached List of Persons Contacted). These physicians and scientists presented clinical data in their fields of medicine where they are using infrared imaging successfully. Some key areas included prognostic, diagnostic, and treatment management applications in the fields of breast cancer, rheumatology, back pain, neuromuscular and vascular disorders, and skin temperature profiles. The following summarizes some of the most significant data presented at this conference:

1. Medical Infrared Systems

The technology used for these systems is primarily first generation scanning systems, but several manufacturers are beginning to use focal plane arrays (FPA). Dorex, Inc., a U.S. company successfully markets both types of systems, having wavelengths 3-5 and 8-12 micrometers. The detector materials are platinum silicide, indium antimonide, and mercury cadmium telluride purchased from Rockwell Intl. Adequate spatial resolution for medical applications can be achieved by utilizing an FPA which contains 256 X 256 elements. Higher performance staring array IR cameras capable of providing signal processing functions to compensate for dead pixles, channel-to-channel gain and off-set from the FPA are under development at Dorex. It appears that Dorex is a small aggressive company that introduces technology innovation and state-of-the-art image processing into their systems. They export a significant amount of their products to Korea.

U.K. manufacturers are trailing behind the U.S. in this technology. Their systems are based on first generation technology e.g. opto-mechanical scanning and require cooling. Several such models are being marketed by Agema Infrared Systems, Ltd. Their top-of-the-line system is Thermovision 1000 (THV1000). Another U.K. company is Rank Taylor Hobson Equipment, Ltd. which produces a high quality system (TICM-II Thermographic Camera) that is used by some prominent hospitals and clinics; one of these is the Rheumatology Department of the Addenbrook Hospital in Cambridge. Systems with uncooled detector technology are being limitedly used. Insight Vision Systems, Ltd. (Malvern) manufactures uncooled, pyroelectric (bolometer) cameras of low resolution (150 pixles). Effort is being focused to convert higher performance military technology (400 pixles) for medical purposes.

A low cost Russian system was exhibited at the conference for marketing in Europe. The system consisted of first generation infrared camera interfaced with a 486 PC for image processing. The total cost of the system was $ 15 - 20K, however the frame rate was 4 frames per second and the resolution was relatively poor. Despite that, they claimed that it is effectively used in clinical applications in Russia. A high performance version is being developed and will be introduced into the market in the very near future. I asked for brochures with specifications for both systems which should be forthcoming. The Russian exhibitors were from the Russian Academy of Science.

In Japan, there are six companies that produce medical infrared cameras in the 3-5 micrometer wavelength region. The detector materials are platinum silicide and indium antimonide in a focal plane array configuration. New developments in this area include mercury cadmium telluride FPA technology.

2. Medical Infrared Applications

Some of the most important applications that were presented by physicians were: skin thermal measurement, breast cancer, vascular. neurosurgery, pre- and post- operative uses, back pain, disc herniations, rheumatology, diabetes, pain management, and dental. A few examples are:

Two-dimensional skin temperature measurement by infrared imaging provides objective classification and monitoring of the peripheral autonomic responses to pain. This leads to more appropriate therapy by objective monitoring of chronic pain patients (W.B. Hobbins)

The usefulness of thermal imaging in detecting breast cancer has been evaluated in the last ten years in different countries. These findings strongly suggest that further studies using more advanced equipment and improved protocols may well result in an effective, non-invasive prognostic technique. Thermal imaging has been used in several cancer management situations. It has been shown that the sensitivity of tumor detection by infrared imaging increases with the malignancy of the tumors, from 44% - 77% (M. Anbar).

In neurological studies, infrared imaging was found to be useful in the diagnosis and management of Carpal Tunnel Syndrome (CTS) in three types of cases: (1) CTS with equivocal and normal elecctroneuromyographic findings, (2) patients with failed carpal tunnel release, and (3) recurrent CTS. In all the aforementioned situations, Infrared Imaging was found to be highly effective, whereas Electromyography (EMG) was not (A. Pavot).

Further, in neuromuscular cases it is important to know the exact symptomatic level in multiple herniations of lumbar discs on CT scan or MRI. Digital Infrared Thermal Imaging (DITI) showed the exact symptomatic radiculopathic pattern in 80.2 % when compared with CT or MRI, and in 84.5% when compared with discometry - CT discogram. Therefore, DITI is a simple and very significant method for the detection of the sympathetic level in multiple lumbar disc herniations (Young-Soo Kim).

Clinical assessments of deep venous thrombosis (DVT) demonstrated that Infrared Imaging was found extremely effective in venous thrombosis. Its use obviated the need for evasive venography with its attendant risk of allergic reactions and harmful exposure to ionizing radiation. Other favorable factors of Infrared Imaging are that it is painless, less time consuming, and significantly less costly (British Pounds 2.66 versus 55.67 per venogram - please note that these are UK prices!)

Conclusion

This conference brought to evidence the wide-spread and successful use of Infrared Imaging in several countries; in some of these it is a part of all medical examinations and fully reimbursed by governments and insurance companies.

My participation in this conference permitted me to establish a working relationship with the key players in this field. Subsequently, this facilitated the very successful symposium on medical dual-use technologies at the IEEE/EMBS International Conference in Baltimore (Nov.3-6, 1994), which was co-sponsored by ARPA and ARO.

The standardization workshop, in which I participated, led to a unanimous consensus to concentrate on developing international standards recognized in all countries. Dr. Raymond Clark, UK, will be the chairman of this working group and he will provide a draft to all the members for review before it is submitted to the European Economic Community Standardization Board for coordination with Asia, Canada and U.S.

The need for statistical significant quantitative clinical data was recognized as a major thrust for all the infrared measurements. These, coupled with standard equipment and methods will definitely give us the further validation required for infrared imaging to be accepted as a vital modality.

PERSONS CONTACTED

Name	Affiliation/Country
Prof. K. Ammer, M.D.	Vienna, Austria
Prof. M. Anbar, Ph.D.	State University of New York Buffalo, N.Y., USA
Prof. I. Benko, Ph.D.	Budapest Technical University Hungary
Prof. R.P. Clark, Ph.D.	King's College, London, UK
Dr. T. Elliott	UK Ministry of Defense Malvern, UK
Prof. Y.E. Cho	Yonsei University, Seoul, Korea
Prof. I. Fujimasa, M.D., Ph.D.	University of Tokyo, Japan
Dr. G. Goldberg, M.D.	Universal Medical Center Plantation, Florida, USA
Dr. J.R. Hading, M.D.	Royal Gwent Hospital Gwent, Wales, UK
Dr. B. Harper	Insight Vision Systems, Ltd. Malvern, UK
Dr. B.L. Hazleman, M.D.	Addenbrook's Hospital Cambridge, UK
Dr.E. Kalodiki, M.D.	St. Mary's Hospital, London, UK
Prof. M.L. Khitrov, Ph.D.	Russian Academy of Sciences Moscow, Russia
Prof. Y.S. Kim, M.D., Ph.D.	Yonsei University, Seoul, Korea
M. Kutas	Dorex, Inc., Orange, CA, USA
Prof. E. Lang	Erlangen University, Germany
Dr. D. Pascoe, M.D.	Auburn University, AL, USA
Dr.A.P. Pavot, M.D.	Georgetown University Medical Center, Washington, D.C., USA
Dr. N. Pothecary	Bristol Oncology Centre, UK

Prof. K. Mabuchi, M.D., Ph.D.	University of Tokyo, Japan
Prof.A.G. Markov	Russian Academy of Sciences Moscoe, Russia
Prof. F.J. Ring, D.Sc.	Royal National Hospital for Rheumatic Diseases, Bath, UK
Prof. G.C. Rockley, Ph.D.	Oklahoma State University, USA
Prof. G. Rodan	Institute of Fluid Mechanics and Flight Dynamics Bucharest, Rumania
Prof. A. Spitzer	Erlangen University, Germany

TRIP REPORT
(Japan, June 17 - 24, 1996)

To: U.S. Army Research Office
ATTN: Procurement Office (Ms. Terry)
Research Triangle Park, NC

From: Nicholas A. Diakides
Advanced Concepts Analysis, Inc.
6353 Crosswoods Drive
Falls Church, VA 22044

Subject: Japanese Society of Thermology Conference, Akita, Japan
Ref: Contract DAAH04-94-C-0020

Date: July 12, 1996

Introduction:

At the invitation of Professor Fujimasa, President of the Japanese Society of Thermology, I went to Japan to present a paper on recent technological advances in infrared imaging (copy of briefing attached). Further, at my request, Professors Fujimasa and Mabuchi, University of Tokyo, arranged for me to visit in Tokyo selective institutions using infrared imaging in their clinics. This took place on June 19, 1996, before my departure to Akita, the conference site.

Discussion:

Visited the Research Center of Advanced Science & Technology, University of Tokyo, where Professor Fujimasa showed me all the various infrared imaging systems they had in operation and we discussed in detail the software development effort for medical infrared imaging at his center. He emphasized the need for software and image processing to be designed for each specific disease in a modular form. This would have the potential of increasing the accuracy and decreasing the cost of the clinical test appreciably. In addition, Professor Fujimasa discussed the critical need for standardization and effective equipment specifications. He also encouraged the continuation of our collaboration.

Professor Mabuchi escorted me around the facilities of the Research Center and showed me the laboratories and research efforts. He informed me that the University of Tokyo plans to establish a division exclusively for infrared imaging in medicine. In Japan, there are 4,000 hospitals (defined by more than 150 beds) and 30% of these (1,200) use infrared imaging routinely. He pointed out, however, that 70% of patients in Japan are treated as outpatients at clinics. Hence, their future objective will be to equip the outpatient centers with infrared imaging systems. The thrust will be to design the cameras and the software in such a way as to decrease the time required for each test and the cost of these.

Later, we visited the Tokyo Cancer Research Hospital where Dr. Yasuhiko Ohashi, M.D., Ph.D., Director of Oncology specializing in breast cancer, presented a large database (more than three thousand patients) which he has developed over the last ten years. He showed us in detail the method he uses for the tests and his unique image processing technique which is based on sequential thermography. The first step entails three views of the breast, followed by a series of fifteen pictures taken sequentially every fifteen seconds. The second step is a computer-generated comparison of the images by subtraction to produce the final result. This enhances the reliability of the measurement.

At this hospital, all breast cancer patients are tested routinely by all the following methods: thermography (cost $20.00), mammography ($40.00), echography ($50.00), and physical examination (30.00). Results of all tests are used for the final diagnosis.

Dr. Ohashi also demonstrated that thermography after mastectomy provides highly effective pathophysiological information. He said that careful and detailed thermographic examination is beneficial after surgery to patients with breast cancer, because it tells you if there is a recurrence and can do so with non-invasive procedures.

The conference in Akita (June 20-22) was held at the conference center of the medical institute where a total of 57 papers were presented. The topics of the papers were very diversified and were in the areas of breast cancer, dental surgery, dermatology, oriental medicine, orthopedics, otorhinolaryngology, pain management and control, peripheral circulation, plastic surgery, and neurology. Most of the presenters were both physicians and Ph.Ds. and were using infrared imaging routinely in their practices. Highlights of some of the papers were:

(1) the Japanese standardization plan presented by Professor Fujimasa,
(2) the results of breast cancer diagnosis and methodology, and post-operative testing presented by Dr.Ohashi, Tokyo Cancer Institute Hospital
(3) efficacy of exercise thermography for evaluation of blood flow after angioplasty in patients with arteriosclerosis presented by Dr. Amano
(4) fluctuations of skin temperature under changing ambient temperature as a function of age presented by Dr. Sugai
(5) effects of spicy foods on skin temperature presented by Dr. Maeda

There were excellent exhibits of five Japanese medical infrared cameras:

(1) AVIO : They demonstrated two thermal video systems (TVS-100ME & TVS-2000 MK). The former is a lower cost system priced at app. $ 35,000.00 and is cooled by a thermo-electric cooler at -60C. This system has automatic internal temperature calibration capability with autofocus. The detector material is MCT and the system operates at ten frames per second. This is mostly used for outpatients. The latter is a higher

performance system costing app. $ 69,800.00 and is cooled by a Stirling Engine Cooler. This system is manually focused and operates at thirty frames per second. The detector material is MCT. The temperature is automatically calibrated internally. This higher performance system is used in hospitals.

(2) JEOL: Displayed one high quality system (JTG-5310) priced at app. $75,000.00 which has autofocus capability. The detector is a MCT starring focal plane array and has liquid nitrogen cooling with long wavelength 8-12 micrometers. The thermal sensitivity of the system is 0.05C and has a frame rate of 0.8 seconds per frame. The detector arrays are purchased from the U.S.(TI). The image processing is done at 16 bits (very deep) and has sensor fusion capability.

(3) FUJITSU/ NIHON KOHDEN: Showed one system "Infra-Eye 1200". The detector array is 30 X 1 and is MCT cooled thermo-electrically at 60C and has automatic temperature calibration internally. The system has a temperature sensitivity of 0.1C. and operates at 15 frames per second. The monitor resolution is 174x240 pixels. The price of this system is $ 70,000,00 and is used by both hospitals and outpatient clinics.

(4) NEC: Demonstrated two systems (TH 3107/3108). The former is a higher cost system and has a single element MCT detector which operates at 7-12 micrometers wavelength. The sensor is purchased from the U.S. (Cincinnati Electronics). It is cooled by a Stirling engine cooler. The system operates at 0.8 seconds per frame and has automatic internal temperature calibration. This system is used primarily in hospitals. The price is $81,000.00. The latter (TH3108) is a less expensive system which costs $49,000.00 and has a single element MCT detector middle IR wavelength capability at 3-5 micrometers. It is cooled by a thermoelectric cooler at -60C. Its thermal sensitivity is 0.1C. It is used in outpatient clinics. Both systems have monitors with resolution 256X270 pixels.

(5) ADVANCE CO. LTD.: This company exhibited a unique laser doppler blood flow and blood volume measurement system, which costs app. $36,000.00. This system compliments infrared imaging and can be used in image fusion. The laser is a 2 milliwatt 780 nanometer wavelength.

In conclusion, the trip was very important in that it allowed me to obtain first-hand information on the successful use of infrared imaging in medicine in multiple applications. Further, the above information on infrared cameras is closely held by the Japanese and is not available in the U.S. One thing that emerged as extremely important was the need for automatic internal temperature calibration as established by the Japanese. The relationships with leaders in this field was strengthened with a view to collaborating in the endeavor to re-establish the use of IR imaging in medicine in the U.S. One important aspect of this will be in the field of standardization and development of functional specifications for IR imaging systems.

TRIP REPORT
(Vienna, Austria, April 29-May 3, 1997)

TO: U.S. Army Research Office
Attn: Procurement Office (Ms. Terry)
Research Triangle Park, NC

FROM: Nicholas A. Diakides
Advanced Concepts Analysis, Inc.
6353 Crosswoods Drive
Falls Church, VA.

Subject: Seventh European Congress of Medical Thermology, Vienna, Austria
Ref: DAAH04-94-C-0020

Date: 5 June, 1996

Introduction:

At the invitation of Dr. Ammer, President of the European Society of Thermology, I went to Vienna to attend the conference and to present a paper on "New Developments in Low Cost IR Imaging Systems" (a copy of the paper is attached). Prior to the conference, I had discussions and visits with Dr.Ammer and his staff concerning the use of infrared in their institute, where several research projects have been conducted, primarily in pain management control.

This was a very well attended conference and there were many new ideas presented. There were participants from Korea, Japan, Taiwan, Germany, Italy, Spain, UK, Austria, Eastern Europe, and the U.S. The topics reflected several new initiatives in the clinical use of infrared imaging in diagnostic, screening, and therapeutic applications. A list of attendees is enclosed, as is the journal " Thermologie" which contains the relevant abstracts. The proceedings of this conference will be published in a later edition.

Discussion:

One of the papers presented by Professor Anbar, State University of New York at Buffalo, reported preliminary results on a new method to measure the fluctuations of temperature derived from the cardiac cycle in quasi-real time.

A study od different areas on human arms showed the propagation of the hemodynamic pulse, demonstrating the potential use of this technique in peripheral hemodynamic investigations. This is a very promising area for understanding the microcirculation of the skin.

Professor Fujimasa, Saitama University, Japan, reported on the creation of his infrared database which is available on the world-wide web. This includes the Japanese requirements and standardization for clinical use. He encouraged the Europeans and Americans to follow suit.

Professor Clark, Cranfield University, presented a draft international standard proposal with guidelines for standardization in medical thermology. The initial work was started at the conference in Bath in 1994, through a workshop in which I participated and emphasized the need for such participation and document. This will help us communicate and exchanged data throughout the world. For example, the digitized images must be standardized in order to be compatible for clinical data exchange.

In fact, it was in Vienna that through initiating serious discussions on the above, we were able to bring together all three guidelines (Japanese, European and US). Professor Clark and the American Academy of Thermology will now continue to work on the refining of these standards.

Professors Ring and Plassmann presented their work on the "B THERM", which is their developed software system for infrared imaging in medicine. Although it is used in the upgrading of old infrared systems to an enhanced performance equivalent to the present systems. The proposed software includes a designed low cost digitizing hardware that allows the infrared imaging systems to be connected to a standard Personal Computer. The digitizer produces 8 bit images with a resolution of 256X256. These capabilities include algorithms for standard statistical operations (histogram, standard deviation, mean, etc.) isotherm generation, cross-sections and color palette manipulation. A special large and clear print format comes as a standard report sheet by a low cost ink jet printer. This always allows a standard report, clearly showing measurement indices and color scale to be sent to the referring physician.

Dr. Maca from the University of Vienna Medical School reported on a pilot study to evaluate the technical feasibility of infrared imaging for control of hemodialysis shunts. His preliminary data was reported as promising to deliver additional facts to alternate methods (duplex sonography or angiography) for terminal renal insufficiency before transplant is done. This paper had a novel application, hence I invited him to give a paper at the IEEE/EMBS conference in Chicago next October.

In the area of breast cancer, there were several good papers, including one from Rumania and other East European countries. It is evident that in Europe infrared imaging in breast cancer is quite widely used. The following are some of the highlights:
Dr. Montruccoli from Toniolo Clinic, Bologna, Italy, reported on his 25 year study of breast cancer lesions involving more than 6,000 women using

angiothermography (ATG). He states that this method reveals lesions' dynamic blood supply. Unlike X-Ray mammography, ATG is effective at any age even in dense breasts, and is capable of revealing pre-neoplastic lesions.

Dr. Ohashi, Cancer Institute Hospital, Tokyo, Japan, gave a paper on the diagnostic significance of IR imaging on patients with breast cancer after surgery. His data shows that IR imaging on these patients demonstrates the pathophysiological conditions of the breast, and that a careful and detailed examination will b e beneficial to them. He also will be presenting as an invited speaker at Chicago.

Breast cancer seems to be of great interest throughout the world, and we will have a whole session on it at the IEEE/EMBS conference.

Conclusions:

There is a marked and significant interest in the use of infrared imaging in medicine, and the quality of the presented papers has improved. We are continuing to encourage scholarly presentations and publishing of results. Further, open and informal discussions were held by us with many of the scientists and physicians, with the purpose of gaining maximum exposure of their work, and continuing to push for better image interpretation and improved system performance, and, of-course, standardization.

These conferences are of extreme value, because goal setting takes place among these physicians and scientists, many times involving collaboration internationally. We intend to press forward with all these goals at the Chicago conference, where we are expecting to have thirty papers on the use of infrared imaging in medicine. The relationships we formed through the conferences has permitted this to happen, with minimum cost.

Enc:

European Association of Thermology

Affiliated to The International College of Thermology

Dr.Nicholas Diakides
Advanced Concepts Analysis, Inc.
6353 Crosswoods Drive
22044 Falls Church, VA
USA
Fax 001 703 914 1636

President: Prof.Dr.R.P.Clark, United Kingdom
Vice-President: Dr.D.Rusch,Germany
Secretary General and **Treasurer:**
Dr. K. Ammer, Austria
Pay to: European Association of Thermology
Bank Austria, Wien/Austria, bank No 20151
Account No 965023054

From : Secretary and Treasurer, Dr.Kurt Ammer
Ludwig Boltzmann Forschungsstelle für Physikalische Diagnostik, Heinrich Collinstr.30, A-1140 Wien /Austria
Tel: + 43-1- 914-97-01 **Fax: +43-1-914-92 64**

Dear Dr. Diakides!

I have the pleasure to inform you, that your paper, titled

New Developments in Low Cost IR Imaging Systems

was accepted for oral presentation at the 7th European Congress of Thermology 1997.

Your time of presentation is

Friday 2nd May, 16.00 to 16.15

Each presentation has been allotted 15 minutes; this will allow 12 minutes for your paper and 3 minutes for questions. Please be so kind, and speak strictly to time, because the programme is very full and we are short of time.

I appreciate, if you would bring a full length version of your presentation to be published in one of the forthcoming issues of "Thermologie Österreich".

I thank you very much for your contribution and support for a successful conference.

Finally, I like to inform you that public transport might be restricted on the morning of May 1st, in Vienna. Therefore early arrival at the congress venue is advised.

Looking forward to meeting you in Vienna

Best regards

Ammer

Kurt Ammer

APPENDIX C

Paper Reprint Published in the European Journal of Thermology

ISSN-1021-4356
Thermol Österr

European Journal of Thermology

formerly Thermologie Österreich

7.Jahrgang (1997)
Heft 4 (Oktober)

Herausgegeben von der

Ludwig Boltzmann Forschungsstelle
für Physikalische Diagnostik

Österreichischen Gesellschaft für Thermologie

New Developments in Low Cost IR Imaging Systems *

Nicholas A. Diakides

Advanced Concepts Analysis Inc.,6353 Crosswood Dr., Falls Church, VA 22044-1209

Summary

Night vision technology is present in most military systems used today. The sensors range from night vision goggles to high performance infrared target acquisition and tracking systems. With the importance placed upon night vision, lower cost and wider availability of night vision technology is an important consideration. Infrared sensors, which do not require cryogenic cooling, have many of these assets. Recently, the excellent imaging performance of uncooled infrared has captured the attention of many system users, and new applications are rapidly emerging. This paper reviews these application areas, explores new possibilities, and assesses the technology underway to further expand the realm of uncooled infrared imaging. Technological advances, both in the sensor technology and the interface with the imaging system, will expand the use of uncooled infrared sensors into additional military and commercial applications. Performance characteristics and requirements will be presented with recommendations.

Keywords: IR Detectors, Focal Plane Arrays, Uncooled IR Imaging Systems, Infrared Imaging Technology.

Neue Entwicklungen bei kostengünstigen Infrarot-Bildsystemen

Nachtsichtgeräte werden heutzutage bei den meisten militärischen Systemen eingesetzt. Die Sensoren decken den Bereich von Nachtsichtbrillen bis hin zu hochempfindlichen Ziel- und Leitsystemen ab. Bei der zunehmenden Bedeutung, die Nachtsichtgeräten zukommt, sind geringere Kosten und allgemeine Verfügbarkeit ein wichtiger Aspekt. Infrarotsensoren, die keiner Kühlung bedürfen, erfüllen viele dieser Anforderungen. Seit kurzem hat die ausgezeichnete Bildgebung ungekühlter Infrarotsensoren die Aufmerksamkeit vieler Anwender gewonnen und neue Einsatzgebiete sind in rascher Entwicklung. Diese Arbeit gibt einen Überblick über Anwendungsgebiete, erkundet neue Möglichkeiten und beurteilt die aktuelle Technologie in Hinblick auf weitere Einsatzmöglichkeiten ungekühlter Infrarotsensoren. Der technologische Fortschritt, sowohl im Bereich der Sensoren als auch die Ankoppelung an Bildsysteme, wird den Einsatz ungekühlter Infrarotsensoren in zusätzliche militärische und kommerzielle Anwendungen ausweiten.Leistungscharakteristik und Anforderungen werden gemeinsam mit Empfehlungen dargestellt.

Schlüsselwörter: IR Detektoren, Focal Plane Arrays, ungekühlte IR Abbildungssysteme, Infrarot Abbildungstechnologie

Introduction

Uncooled infrared focal plane arrays are generally thermal detectors, which respond to temperature changes in the detector. The detector material properties are proportional to changes in the detector temperature. The most common thermal detectors are classified as either:

1.) microbolometers
(temperature dependent resistance),

2.) ferroelectrics
(temperature dependent dielectric constant), and

3.) thermally sensitive metal-semiconductor junctions (temperature dependent current change).

Currently, the thermal detectors are fabricated using primarily silicon fabrication technology, which leads toward large arrays and conventional fabrication technology.

* Presented at the 7th European Congress of Thermology in Vienna, 1-3 May 1997

UncooledIR Detector /Focal Plane Array Status

Thermal detector arrays are designed in both hybrid and monolithic architectures. In the hybrid design, the detector is indium bump bonded to a silicon signal processor. The indium columns form both the electrical connection between detector and signal processor, and a thermal conduction path to the silicon. The thermal conduction must be minimized to maximize the temperature differential across the detector and achieve high sensitivity. In the monolithic design, the detector is deposited on an isolation structure fabricated on the silicon signal processor. The monolithic thermal isolation structure typically provides a lower thermal conduction than the indium columns in the hybrid structure. Ultimately, the monolithic structure is the preferred architecture for each of the thermal detectors, ferroelectric, microbolometer, and ther- mally sensitive junctions (7, 9).

A number of ferroelectric material candidates are available. The most advanced is a bulk-grown Barium Strontium Titanate (BST) material, which has been fabricated using a hybrid architecture in 320 x 240 element arrays. These arrays have been integrated into imaging systems. Since the detector responds to a change in polarization, an external chopper is required to provide a reference temperature for each frame. Sensitivity, less than 0.1°C, measured with this detector is adequate for many applications.

The other general class of uncooled detectors is microbolometers, which respond to a temperature change with a change in their resistance. The microbolometer resistors are deposited on a suspended microbridge structure, which isolates the detector thermally from the silicon substrate. Electrical connection is made through the thin leg of the microbridge. Microbolometer arrays have been fabricated using vanadium dioxide and polysilicon as the sensing material. Unlike the ferroelectric detectors, these are direct coupled detectors and generally do not require an external chopper. Imaging demonstrations with the vanadium dioxide microbolometer have also shown sensitivity of less than 0.1°C in array sizes of 320 x 240. Images were obtained without the use of an external chopper. This is accomplished through correction of the detector offsets, both at the detector and in the subsequent processing. Thermopile arrays of 128 x 128 elements have also been demonstrated with thermal sensitivity of 0.5°C. The thermopile array consists of an IR absorber and a thermally sensitive junction. The voltage change at the thermal junction is sensed through charge accumulation in a charge coupled device (6).

Performance Enhancements

The ferroelectric detectors are also being designed as a monolithic structure to take advantage of the thermal isolation of the microbridge. The major challenge is the deposition of thin ferroelectric films at deposition temperatures compatible with the silicon processing.

Current microbolometer technology has the potential for greater sensitivity than the currently demonstrated 0.1°C (3). Near-term projections indicate that a Noise Equivalent Temperature Difference (NETD) of 0.02°C is practical, with theoretical predictions of 0.01°C (8). The combined improvement from near-term design and material enhancements in each of these areas will improve sensitivity by greater than a factor of five. Efforts are under way to improve the performance of the uncooled IR detectors by employing innovative signal processing and sensitivity enhancement techniques. To accomplish this, the following technology challenges are being addressed:

1.) incorporation of electronic functions on the sensor chip for image processing - this will reduce the system integration cost and will increase the signal-to-noise,

2.) increasing sensitivity through trade-off analysis by using smaller optics size thus lowering the cost,

3.) faster detector response for specialized applications which will result in a more versatile sensor,

4.) reducing pixel size in order to lead to larger F numbers and fabricate large, high density arrays,

5.) development of uncooled sensor prototype systems to demonstrate improved performance. (4).

Uncooled Focal Plane ArrayApplications

Uncooled IR sensor performance improvements and the demonstrations of fieldable camera systems have led to the emergence of new and exciting applications for uncooled IR systems.

The potential applications in both the commercial and military systems are quite large, and growing, as the camera performance continues to improve. These applications include law enforcement, night driving, industrial process control, environmental monitoring, and medicine. This paper will address only the medical uses since currently low cost diagnostic systems are needed in health care. Infrared imaging is a highly useful, harmless, inexpensive clinical technology that is being used successfully in many countries (1). The following are some of the major areas where infrared imaging systems are being used successfully: neurology, vascular disorders, rheumatic diseases, pain, tissue viability, oncological and breast cancer, dermatological disorders, neonatal, ophthalmology and surgery (5). The first five already are being used clinically and the others are in the experimental stages. This generates potential opportunities for more clinical research to determine quantitatively the benefits of advanced thermal imaging in comparison to other modalities. Further, it is necessary to highlight the scope of various applications of IR imaging and assess its precision and replicability with practical interpretation of results.

Conclusions

Significant advancements in uncooled IR and image processing technologies have been achieved by Defense Advanced Research Projects Agency (DARPA) and Department of Defense laboratories to date (2). Uncooled sensors have demonstrated high quality imaging with thermal sensitivity better than 0.1¡C and resolution less than 1.0 milliradians. Present capability in both sensitivity and resolution meets the performance requirements of 75% of all medical applications. Current performance enhancements will provide benefits to the user (size, weight, power, cost). It is anticipated that the total cost of the uncooled IR imaging system including the image processing package will be less than USD $20,000. The clinical utilization of IR imaging needs to be reevaluated in view of the availability of the latest advanced technology. There are opportunities to involve academic medical institutions in quantitative studies of IR imaging research and have results published.

References

1.) *Anbar M.: Quantitative and Dynamic Thermal Imaging in Medical Diagnosis. CRC Press, 1994.*

2.) *Balcerak R., D.P. Jenkins: Uncooled Infrared Focal Plane Arrays, Proceedings, 18th International Conference of the IEEE Engineering in Medicine and Biology Society, Amsterdam, November 1996*

3.) *Butler N., R. Blackwell, R. Murphy, R. Silva, C. Marshall: Low Cost Uncooled Microbolometer Imaging System for Dual Use. SPIE Vol.2269 Infrared Technology XX, 1994*

4.) *Diakides N.A., R. Balcerak: Recent Technological Advances in Infrared Imaging. Proceedings, 25th Annual Meeting of American Academy of Thermology Las Vegas, NV March 29-30, 1996.*

5.) *Diakides N.A., D.P. Jenkins: _Medical Uses of Infrared Sensors. Proceedings, National Infrared Information Symposium, Laurel, MD, July 11-12, 1995.*

6.) *Kanno T., M. Saga, S. Matsumoto, M. Uchida, N. Tsukamoto, A. Tanaka, S. Itoh, A. Nakazato, T. Endoh, S. Tohyama, Y. Yamamoto, S. Murashima, N. Fujimoto, N. Teranishi; Uncooled Infrared Focal Plane Array Having 128 x 128 Thermopile Detector Elements. SPIE Vol. 2269 Infrared Technology XX, 1994.*

7.) *Kulwicki B., A. Amin, H. Berratan, C. Hansen; Pyroelectric Imaging, IEEE Proceedings Sept. 1992.*

8.) *Piotrowski J., W. Gawron, Z. Djuric: New Generation of Near-Room Temperature Photodetectors. Optical Engineering. 33;/5: 1413, 1994*

9.) *Ueno M., O. Kaneda, T. Ishikawa, K. Yamada, A. Yamada, M. Kimata, M. Nunoshita: Monolithic Uncooled Infrared Image Sensor with 160 x 120 Pixels. SPIE Vol. 2269 Infrared Technology XX, 1994*

Address of the author
Nicholas A.Diakides, Ph.D.
Advanced Concepts Analysis Inc.,
6353 Crosswood Dr.,
Falls Church, VA 22044-1209
diakides@snap.org

(Manuscript received on 3.5.1997, accepted on 20.6.1997)

APPENDIX D

Abstracts of Papers in Medical IR Imaging
from Proceedings of the IEEE/EMBS International Conferences
(1994 - 1997)

Engineering Advances:
New Opportunities for Biomedical Engineers

IEEE Engineering in Medicine and Biology Society
16th Annual International Conference
November 3-6, 1994
Baltimore, Maryland

SYMPOSIUM ON

MEDICAL DUAL-USE TECHNOLOGIES

Organizers:

Donald P. Jenkins,
Nicholas DeClaris*
Nicholas Diakides**

SESSION VI: MEDICAL INFRARED IMAGING

The goals of this symposium are (i) to assess the current and future potential of a number of key technology areas of special interests to ARPA and to biomedical engineers and educators, and (ii) to define the directions of future research in these interdisciplinary areas. Invited experts will summarize recent developments in their research area. Panel discussions, with audience participation, will focus on the challenges and benefits in advancing the technologies.

Sponsored by:
Advanced Research Projects Agency, Defense Sciences Program,
***the University of Maryland, Medical Informatics Laboratory, and**
****the U.S. Army Research Office**

EMB

IEEE

Engineering Advances:
New Opportunities for Biomedical Engineers

IEEE Engineering in Medicine and Biology Society
16th Annual International Conference
November 3-6, 1994
Baltimore, Maryland

16TH ANNUAL INTERNATIONAL CONFERENCE OF THE IEEE EMBS
1994
BALTIMORE

SYMPOSIUM on MEDICAL DUAL-USE TECHNOLOGIES
SESSION 6: MEDICAL INFRARED IMAGING

Saturday, November 5, 1:30 - 4:30, Pratt Room

Co-chairs:	Raymond Balcerak, Microelectronics Technology, ARPA Alfred Pavot, M.D., Georgetown Univ. Medical Center
1:30 - 1:50	**Thermology in the 21st Century - the Biomedical Future of a Technology Based on Defense Oriented Engineering.** Michael Anbar, Ph.D., School of Medicine and Biological Sciences, SUNY, Buffalo.
1:50 - 2:10	**The Role of Thermography in the Diagnosis and Treatment of Breast Cancer.** Robert Elliott, M.D., Ph.D., Fen Wang, M.D., Michael W. Haley, M.D., and Jonathan Head, Ph.D., The Elliott Mastology Center, Baton Rouge, LA.
2:10 - 2:30	**Pre- and Postoperative Digital Infrared Thermographic Imaging in Lumbar Disc Herniations.** Young-Soo Kim, M.D., DMSc., Yonsei University College of Medicine, Seoul, KOREA
2:30 - 2:50	**Quantitative Thermal Imaging in Rheumatology.** Francis Ring, D.Sc., Royal National Hospital of Rheumatic Diseases, Bath, U.K.
2:50 - 3:10	**Clinical Infrared Thermal Image Testing: a Non-invasive Expression of Invisible Physiological Functions.** Iwao Fujimasa, M.D., Ph.D., University of Tokyo, JAPAN
3:10 - 3.30	**Low Cost Uncooled Thermal Imaging.** Charles Hanson and Bill Stearns, Texas Instruments, Dallas, TX.
3:30 - 3:50	**Rockwell's Low Cost, High Resolution IR Sensors Make IR Imaging Available to the Medical Community.** James Gilpin, Rockwell International, Anaheim, CA.
3:50 - 4:10	**The Clinical Utility of Thermology.** Gerald S. Goldberg, M.D., Pain Care Center, Plantation, FL.
4:10 - 4:25	Panel Discussion (Questions and Answers).

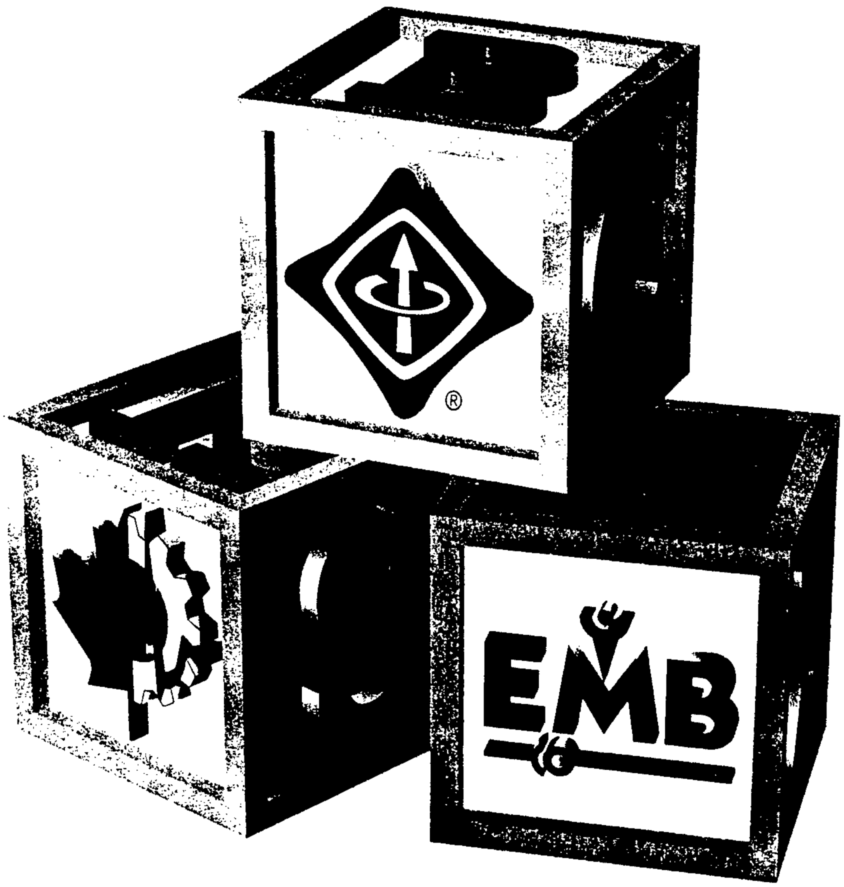
EMB

MONTRÉAL . CANADA - September 20-23, 1995

1995 IEEE Engineering in Medicine & Biology 17th Annual Conference

&

21st Canadian Medical and Biological Engineering Conference



Basic & Applied Biomedical Engineering
Building Blocks for Health Care

Fernand A. Roberge
Conference Chair

Robert E. Kearney
Program Chair

CMBES SCGB

IEEE

EMB

7.1.12.4 Stimuli Generator Dedicated for an Implantable Visual Miniaturized Stimulator

Boyer, Alain; Sawan, Mohamad M. *École Polytechnique, Montréal (Canada)*

A new flexible stimuli generator intended for a miniaturized implantable visual prosthesis has been developped. The device is based on a finite state machine (FSM) and uses 15-bit command words to generate various types of stimuli. Amplitude, pulse duration and interphase duration are the main programmable parameters of each stimulus. In addition, 3 built-in basic shapes allow the generation of a wide range of biphasic stimuli needed for our application. The proposed generator has been synthesized with VHDL language through a BiCMOS 0.8μ technology.

7.1.12.5 A Novel Vibrator for the Diagnosis of Spinal Intradiscal Pain

Takalo-Kippola, Heikki; Lappalainen, Pentti; Yrjämä, Matti; Vanharanta, Heikki. *Univ. of Oulu, Oulu (Finland)*

This paper describes a novel vibrator to stimulate human lumbar spinal processes for the diagnosis of low-back deseases. The vibrator is electrically powered portable medical device. The frequency and the amplitude of the vibrator are adjustable to improve diagnostic performance of the system. Preliminary clinical tests are reported.

THEME 8: DEVELOPING AREAS

TRACK 8.1: MEDICAL INFRA-RED IMAGING AND TECHNOLOGY TRANSFER

Session 8.1.1: Infra-Red Imaging I: Saturday Sep 23 08:30 - 410C [slides]

8.1.1.1 Criteria for Thermal Imaging in Medicine

Ring, Francis. *Royal National Hosp. for Rheumatic Diseases, Bath (U.K.)*

The human body depends on heat transfer from the skin for thermoregulation. Infra red imaging is the most efficient technique for the study of skin temperature distribution. Real time thermal imaging is achieved with modern detectors, usually cadmium mercury telluride detector cooled by liquid nitrogen. By standardising the examination conditions, and calibrating the thermal imager, accurate two dimensional measurements of temperature patterns can be made. Many studies have been performed which show the anticipated normal pattern of temperature shown in a thermal image. In specific diseases, characteristic changes can be measured from target anatomical sites. In this way, objective non-invasive investigations can be of diagnostic value. The technique is especially useful for the monitoring of treatment, whether surgical, physical or pharmacologic.

8.1.1.2 Correlation of Pain Severity with Thermography

Kim, Young-Soo. *Yonsei Univ., Soul (South Korea)*

Thermography can detect the discogenic pain in lumbar disc herniation and change the subjective pain into objective color image. The sensitivity and specificity of thermography are very high as 89.5%, 79.1% and it showed high correlation with postoperative clinical result. So it has been used for diagnosis of disc herniation, detection of symptomatic level in multiple disc herniation and prediction of postoperative courses in lumbar disc herniations. The severity of pain in disc herniation is different according to duration of symptom, types of disc herniation, degree of protrusion and other numerous factors. Author analyzed the thermographic findings of lumbar disc herniation focused on the thermal difference and correlated the thermal difference with severity of pain in 147 patients of lumbar disc herniation. The patients has single level disc herniation with unilateral leg pain and were grouped into acute(78 cases) and chronic(69 cases) group according to duration of symptom. In acute disc herniation group, significant thermal difference is noted according to subjective pain severity ($P< 0.05$), degree of protrusion ($P<0.01$) and type of herniations ($P<0.05$). In chronic disc herniation group, thermal difference is not correlated with severity of pain and disc protrusion. In conclusion, thermal difference is well correlated with severity of pain in acute disc herniation. Thermography is useful for differention of acute and chronic disc herniation and it shows the severity of discogenic pain in lumbar disc herniations.

8.1.1.3 Thermal Imaging in the Investigation of Deep Venous Thrombosis

Harding, J. Richard. *St. Woolos Hosp., Newport (U.K.)*

Preliminary assessment of clinically suspected deep venous thrombosis (DVT) of the lower limb by thermography avoids the need for over one third of venograms or duplex Doppler ultrasound scans. Clinical diagnosis of DVT is notoriously unreliable - hence the need for an accurate means of clinical investigation. Untreated DVT is dangerous as it can progress to pulmonary embolism (PE) which is frequently fatal or life-threatening. Treatment of DVT by anticoagulation poses risks of its own however, and should not be undertaken without a confirmed diagnosis. Thermal imaging is quick, simple, non- invasive, risk-free, cost-effective and highly sensitive in the initial investigation of suspected DVT; a negative thermogram excludes DVT and avoids the necessity for further investigation. Thermal imaging is, however, non-specific; a positive thermogram has a number of possible causes and is an indication for further assessment by venography or Doppler ultrasound to confirm or exclude DVT. Thermography should be considered the initial investigation of choice in clinically suspected DVT, proceeding to venography or Doppler ultrasound only when thermography is positive.

8.1.1.4 Use of Thermal Rhythmography for the Evaluation of Autonomic Nervous Function

Mabuchi, Kunihiko; Chinzei, Tsuneo; Nasu, Yoshiro; Genno, Hirokazu; Fujimasa, Iwao. *Univ. of Tokyo, Tokyo (Japan)*

In this study, the changes in skin blood flow and skin temperature with healthy subjects and the difference in the distribution of the rhythms of skin temperature between healthy subjects and patients with Raynaud's syndrome was analyzed using laser doppler flow meters, thermocouples and a thermographic system (thermal rhythmo-graphy) which is capable of displaying topograms of the power spectra of an arbitrary frequency range with respect to changes in skin temperature. The results showed that the periodic fluctuations of skin temperature may provide a useful index for autonomic nervous conditions, and thermal rhythography could become a useful tool for the evaluation of autonomic dysfunction or for the preventive diagnosis of neuro-vascular diseases such as Raynaud's syndrome.

8.1.1.5 The Use of Infrared Imaging in Laparoscopic Surgery

Marcucci, Lisa; Coletta, Anthony; Aceti, John; Endres, Vince; Moritz, Michael. *Thomas Jefferson Univ., Philadelphia (U.S.A.); Bryn Mawr Hosp., Bryn Mawr (U.S.A.); David Sarnoff Research Ctr., Princeton (U.S.A.)*

Laparoscopic infrared (IR) imaging was investigated as an adjunct to improve visualization of the anatomic structures and tissues critical to successful laparoscopic surgery. In this experiment, a pneumoperitoneum was induced in an anesthetized pig. An IR sensitive camera was inserted into the abdomen with visualization of the bowel, liver, and hepatic hilar structures. These imaged features were enhanced via small temperature changes induced in the tissues by cool CO2 insufflation and hot electrocautery.

Session 8.1.2: Infra-Red Imaging II: Saturday Sep 23 10:30 - 410C [slides]

8.1.2.1 Update in Interventional Digitalized Infrared Thermal Imaging in Pain Management

Leroy, Pierre Louis. *Delaware Pain Clinic, Newark (U.S.A.)*

Abstract not available

8.1.2.2 Converting Algorithms for Detecting Physiological Function Changes from Time Sequential Thermal Images of Skin Surface

Fujimasa, Iwao; Chinzei, Tsuneo; Mabuchi, Kunihiko. *Univ. of Tokyo, Tokyo (Japan)*

Temperature of skin surface closely relates to physiological functions which control body temperature constant. When we intend to analyze such physiological functions from thermal images of skin surface which are obtained by a far infrared thermograph, we should prepare an algorithm to convert from thermal to other physiological information. The temperature of skin surface is influenced many environmental, physiological and structural parameters. When we wish to detect a pathophysiological function, especially, changes of the parameter, we should develop some methods to eliminate the other parameters. The computed thermography system (CTS) developed in 1986 offers fundamental sequential image processing tools. Using this tool, we developed some algorithms to detect transient changes of some physiological functions when we applied thermal, physical hormonal and neural stress. We obtained images, i.e. therma-tomes, which are caused by changes of such physiological functions as skin blood flow rate, blood volume in subcutaneous vascular bed, sweat volume and activities of sympathetic nerve systems.

8.1.2.3 Temperature Measurement in Paget's Disease of Bone

Ring, Francis; Elvins, David M. *Royal National Hosp. for Rheumatic Diseases, Bath (U.K.)*

Paget's Disease of Bone, identified over 200 years ago is characterised by altered bone metabolism, increased heat and bending of long weight bearing bones such as the tibiae. Infra red thermography is an efficient means of monitoring the temperature changes over actively diseased bone. Fundamental studies to determine the cause of temperature changes have been made, using a mathematical model of heat flow in the tibia. These indicate that high osseous vascularity as the major cause of temperature increase. Changes in temperature often precede clinical response to treatment or remission. A series of case studies using Calcitonin, and also Etidronate therapy for periods up to 4 years, have been recorded using a Thermal Index. Quantitative thermography is the ideal means of monitoring the progress of the disease and its treatment.

8.1.2.4 The Inframetrics ULTRA Program and Its Application to Medical Thermography

Teich, Jay S. *Inframetrics Inc., North Billerica (U.S.A.)*

Through the development of a new sensor technology currently underway in its ULTRA Program, Inframetrics expects to reduce I.R. camera costs enough to encourage widespread use in a number of new markets, including Medical Thermography.

8.1.2.5 Infrared Sensor Technology

Marshall, C.; Parker, T.; White, Timothy. *Loral Infrared & Imaging Systems, Lexington (U.S.A.)*

The introduction of uncooled microbolometer infrared (IR) technology is rapidly changing the face of IR imaging for both military and commercial users. Needs previously met with many high cost systems based upon photoconductive technology, image intensifier tubes, scanned FLIRs, or commercially available staring MWIR detectors, can now be met or surpassed with Loral Infrared & Imaging Systems (LIRIS)'s low cost uncooled products. Uncooled microbolometer technology is setting the new standard for user expectations by providing moderate performance at very low cost with low maintenance. By providing both the military and commercial markets with low cost, high performance products able to meet many imaging infrared sensor applications, new markets, users, and applications are being discovered. Much of the interest in uncooled microbridge imaging technology stems from the cost benefit to any potential user. This paper discusses the numerous technical advantages of our microbolometer technology, provides brief descriptions of the technology, the products available from LIRIS, and technology and producibility innovations that are ongoing at LIRIS.=

Session 8.1.3: Panel on Technology Transfer: Saturday Sep 23 16:30 - 410C [slides]

8.1.3.1 Technology Transfer/Transition Methodologies for Medical Applications as Part of the Innovative and Unconventional Concepts Task

Hopmeier, Michael J. *United States Air Force Wright Lab., Eglin AFB (U.S.A.)*

Traditional Technology Transfer has primarily consisted of locating commercial applications for technologies developed within the National Laboratory structure and endeavoring to enter into some form of agreement between the government and industry partner/s to commercialize the further development and disposition of these technologies. The Innovative and Unconventional Concepts (IUC) Task has taken a somewhat different direction. Specifically, a concerted effort is being made to locate new and novel applications for existing technologies within the government as opposed to entering into new development programs for commercialization. The advantage is twofold: first, government needs are met first and with highest priority and second, when a technology is finally transferred, it is closer to the needs of the commercial environment. This results primarily from the fact that the vast majority of commercial enterprises are represented, at least in microcosm, within the federal government. This paper deals specifically with efforts supporting Medical Applications.

8.1.3.2 The National Medical Technology TestBed

Castelaz, Patrick F. *Loma Linda Univ. Med. Ctr., Yorba Linda (U.S.A.)*

The objective of the Loma Linda University Medical Center (LLUMC) National Medical Technology TestBed (NMTB) Program is to promote development and application of the established and evolving defense technology base to obtain dramatic improvements in healthcare delivery in both the battlefield and civilian healthcare sectors. Specifically, its current goal is to significantly enhance the quality and delivery of medical care to combat casualties, with corresponding applicability to civilian trauma care.

8.1.3.3 Parallel Algebraic Logic (PAL): A Dual Use Technology

Coffield, Patrick C. *Wright Lab., Eglin AFB (U.S.A.)*

This paper addresses an emerging technology that is applicable to biomedical digital imagery in general. We specifically address mammography as a first application. Researchers in every major university medical center and several national laboratories are experimenting with diagnostic methods in digital mammography that show promise for earlier detection. In most cases, these advanced methods are computationally intensive. Without the aid of advanced, real-time, computing technology such methods are not suitable for a screening system. What is needed is a hardware and software combination that is capable of evaluating all of these promising methodologies. Theoretical studies at the Armament Directorate have shown that the high-speed computing technology being developed for smart weapons may be able to meet that challenge.

8.1.3.4 Ultrasonic Battlefield Imager

White, Timothy; Nicoli, Anthony; Butler, Neal; Lasser, Marvin. *Loral Infrared & Imaging Systems, Lexington (U.S.A.); Marv Lasser Inc., Rockville (U.S.A.)*

Loral has demonstrated a 42x64 element ultrasound transducer array and C-scan camera. This will be followed by a 128x128 array and camera during the second phase of the program. Overcoming the one coax wire per element constraint of conventional ultrasound systems, gathering 3-D data, and presenting it in a user friendly format enables system design concepts previously considered impossible.=

8.1.3.5 Acoustic Monitoring Pad

Scanlon, Michael V. *U.S. Army Research Lab., Adelphi (U.S.A.)*

The Army Research Laboratory has developed a sensor technology to monitor patient condition by gathering and analyzing acoustic data. Acoustic signature analysis can indicate cessation of breathing or heartbeat. Advanced signal-processing techniques can determine the proper level of response for the indicated condition, and alert attendants via transmitter or alarm that immediate attention or resuscitation is necessary. This sensor pad can be permanently attached to an evacuation stretcher, gurney, or field hospital operating table, or it can also be placed on an injured soldier's torso to continuously monitor heartbeat and breathing. The excellent coupling between the human body and the sensor pad gives a high signal-to-noise ratio over ambient sounds, which may allow medical personnel to detect fluid in the lungs, an obstructed airway, or an irregular heart beat. This information can be transmitted by radio to more qualified medical personnel for remote diagnosis. If soldiers were equipped with a small monitoring sensor pad to carry in contact with the torso, squad performance level could be assessed or those missing in action could be medically interrogated from a remote location, for not only the heart and breathing sounds, but also some of the ambient acoustics that could include the soldier's own speech. The technology can also be used to monitor apnea or Sudden Infant Death Syndrome, or to alert operators of vehicles or aircraft that the pad has detected the onset of sleep, characterized by a decrease in heart and respiratory rates.

8.1.3.6 DTIC - Your Information Source for Defense Conversion/Dual Use Technologies

Cupp, Christian M. *Defense Technical Information Ctr., Alexandria (U.S.A.)*

As central component of the Department of Defense's Scientific and Technical Information Program (STIP), the Defense Technical Information Center (DTIC) contributes to the management and conduct of

Final Program & Abstract Book

18th Annual International Conference
of the IEEE Engineering in Medicine and Biology Society

31 October - 3 November 1996
RAI International Exhibition and Congress Centre,
Amsterdam, The Netherlands

Co-sponsored by the International Federation of Medical and Biological Engineering,
In co-operation with the European Society for Engineering and Medicine

"Bridging Disciplines For Biomedicine"

IEEE EMB IFMBE

Destination Holland

preparation of Langmuir-Blodgett (LB) polymeric films made from pyrrole monomers functionalized with alkyl chains of variable length. The structural and electrical properties of such films are investigated.

8.1.1-3 Saturday November 2, 11h30-11h45
Surface Modification of y-Al2O3 Filters by Chemisorption of Alkyltrichlorosilane Molecules

C.R. Tamanaha, Y. Mendelson and R.A. Peura
Worcester Polytechnic Institute

Surfaces of aluminum oxide (g-Al2O3) filters with 0.02 um pores were modified for biomembrane-mimetic formation by chemisorption of alkyltrichlorosilane molecules. A water-masking process was employed to protect the pores from involvement in the reaction. Characterization was carried out using contact angle measurements, atomic force microscopy, and grazing incidence IR spectroscopy. A protocol was developed from these measurements that resulted in a near monolayer distribution of alkyltrichlorosilane molecules across the filter surface.

8.1.1-4 Saturday November 2, 11h45-12h00
Novel All-Silicon Sensor Structure with Integrated Poly-Si Electrodes

L. Montelius. T.G.I. Ling and J.O. Tegenfeldt Lund University

Abstract The interest in miniaturization of modern chemical and medical sensors is steadily increasing However. when employing methods and fabrication procedures especially developed for microelectronics, one may encounter new and unpredictable problems for applications in aqueous media. For instance, in microelectronics often a dual metal layer system is employed for making electrical contacts. In a solution such a contact may result in galvanic reactions and/or may dissolve in the cleaning agents used for sterilization of medical devices. To address such issues we have employed an all-silicon based process technology for fabrication of sturdy and reliable devices with integrated poly-Silicon electrodes that tolerate most chemical environments. In this presentation we will report on the first results using such electrodes. A comparative study between identical poly-Si and Aluminium electrodes was made in order to investigate the usefulness of poly-Si electrodes We will also demonstrate the nice possibility to use well-documented methods for surface modifications using silane coupling chemistry We believe this added benefit for the silicon based electrodes of easy surface modification processes as compared with metal electrodes, to be extremely valuable for the development of accurate and tailored sensor structures for specific applications

8.1.1-5 Saturday November 2, 12h00-12h15
Use of Atomic Force Microscopy to Probe Surface Charge Densities in Electrolyte Solutions on a Nanometer Scale

R. Raiteri. S. Martinoia. M. Grattarola and H-J. Butt
University of Genoa

The use of Atomic Force Microscopy (AFM) to investigate the surface of hybrid bio-electronic devices is proposed. This work is focused on the determination of charge densities on insulating layers immersed in electrolyte solutions. Computer simulations which model the tip-to-sample interaction forces are discussed. The expression for electrostatic interaction takes into account the H+ density distribution. according to the site binding theory. Experimental data, obtained by operating two commercial microscopes in the force versus distance mode , are therefore compared to the simulated ones. As a result of the comparison, the amount of charge density on SiO2 surfaces is estimated as a function of pH Possible extensions of the model to include dipole layers are also briefly discussed

8.1.1-6 Saturday November 2, 12h15-12h30
Dipole Monolayers: a Model for Elementary Information Processors

S. Cincotti, M. Storace, M. Parodi and A. Chiabrera
University di Genova

A 2-D array of electric dipoles contacted by suitable electrodes is shown to offer paramount properties necessary for intelligent processing of information. On the basis of a simplified mechanism that models the interactions among the dipoles and between the dipoles and the external electrodes, the possibility of transforming the 2-D dipole array into an elementary molecular processor is explored

8.2.1: Infrared Imaging in Medicine I - Technology and Systems - chair: D.P. Jenkins & Francis Ring [Orals]

8.2.1-1 Friday November 1, 15h00-15h15
Uncooled Infrared Focal Plane Arrays

R. Balcerak and D.P. Jenkins Advanced Concepts Analysis Inc.

Night vision technology is present in most military systems used today. The sensors range from night vision goggles to high performance infrared target acquisition and tracking systems. With the importance placed upon night vision, lower cost and wider availability of night vision technology is an important consideration. Infrared sensors, which do not require cryogenic cooling, have many of these assets. Recently, the excellent imaging performance of uncooled infrared has captured the attention of many system users, and new applications are rapidly emerging. This paper reviews these application areas, explores new possibilities, and assesses the technology underway to further expand the realm of uncooled infrared imaging. Technological advances, both in the sensor technology and the interface with the imaging system, will expand the use of uncooled infrared sensors into additional military and commercial applications.

8.2.1-2 Friday November 1, 15h15-15h30
Digital Infrared Imaging for Medicine Recent Advances in I.R. Focal Plane Array Imaging Technology

J.S. Teich Inframetrics Inc.

Thermal imaging has been in use for defense, scientific and industrial applications for more than 25 years. During the most recent five years, however, the rate of change of technology in this field has increased exponentially. As we would always like to see with technological developments, the result has been higher levels of performance, improved ease of use, and lower cost. In the field of medical thermography, the most significant new technological achievement is the commercialization of the staring focal plane array (FPA) detector and its incorporation in a calibrated thermography system. This paper describes the development of the ThermaCAM® calibrated digital FPA thermography system and its application to the technique of thermal coronary angiography (TCA) The use of the ThermaCAM for TCA in a multiroom cardiac surgical suite is also described

8.2.1-3 Friday November 1, 15h30-15h45
Uncooled Infrared Sensor with Digital Focal Plane Array for Medical Applications

T. White, Ch. Marshall and N. Butler Lockheed Martin IR Imaging Systems

Lockheed Martin IR Imaging Systems is developing low cost, high performance, uncooled infrared imaging products for both military and commercial applications. These products are based on the microbolometer technology, a silicon micromachined sensor which combines the wafer level silicon processing with a device structure capable of yielding excellent infrared imaging performance. Here, we report on the development of an uncooled sensor, the LTC500, which incorporates an all digital focal plane array and has a measured NETD of less than 70 mK The focal plane array and the electronics within the LTC500 have been designed as an integrated unit to meet a broad range of end user applications by providing features such as nonuniformity correction, autogain and level, NTSC and PAL video, and digital outputs. The 327 x 245 element focal plane array has a 46.25 mm pixel pitch and an on focal plane array 14 bit to analog to digital converter (ADC) These features will make possible economical digital IR imagery for quantitative as well as qualitative medical applications

8.2.1-4 Friday November 1, 15h45-16h00
Recent Advances in Portable Infrared Imaging Systems

M.W. Grenn US Army Night Vision and Electronic Sensors

Significant progress in the manufacturing of photovoltaic HgCdTe and InSb, Schottky barrier PtSi, uncooled ferroelectrics and microbolometers, and quantum well infrared detector technologies has occurred over the last 5 years, enabling system developers to obtain high quality staring infrared focal plane arrays (IRFPAs) at a reasonable cost. Recently developed portable IR imagers using 256x256 and 320x240 staring IRFPAs have achieved thermal sensitivity unmatched by systems typically used for medical studies in the past. Cooled staring systems weighing less than 3 pounds have demonstrated thermal sensitivity below .020 degrees C. more than a factor of 10 improvement over comparably packaged first generation serially scanned systems. The use of high quantum efficiency (QE) staring IRFPAs offers design flexibility and performance tradeoffs that until recently were impractical. Portable cooled staring systems operating in the short (1-2.5 micron), medium (3-5 micron), and long (8-12 micron) wavelength IR spectral bands provide excellent image quality at nominal video frame rates Staring systems can be tailored to maintain sensitivity at high frame rates and over narrow spectral bandwidths. The medical benefits associated with high sensitivity thermal imaging, calibrated radiometric imaging, wavelength and time resolved spectrometry, and realtime sensor fusion have not been fully explored. An uncooled head mounted thermal imager (HMTI) weighing 1.25 pounds is being developed by the US Army Night Vision and Electronic Sensors Directorate to assist in combat casualty care and confined environment search and rescue.

8.2.1-5 Friday November 1, 16h00-16h15
Biomedical Application of High-Resolution Infrared and Parallel Processing Technologies

P.C. Coffield and C.E. Gooden US Air Force Wright Laboratory

Abstract-- The Armament Directorate is developing a high-resolution infrared focal plane array and a massively parallel image processor for smart weapons technology. This paper addresses the emergent applicability of these technologies to biomedical digital imagery in general. We specifically address this infrared data acquisition and processing combination for its potential application in the areas of intervention surgery, pathology, thermography, and anesthesiology. Researchers in major university medical centers and several national laboratories are experimenting with diagnostic methods involving digital infrared systems. In many cases, these advanced methods are computationally intensive. Without the aid of advanced, real-time computing technology such methods are not suitable for real-time operative procedures. A hardware and software combination capable of evaluating all of these promising methodologies is needed.

8.2.1-6 Friday November 1, 16h15-16h30
Improving the Resolution of Infrared Images of the Breast

W.E. Snyder and C. Wang North Carolina State University

An algorithm is described which performs a 2:1 zoom on a infrared image of the breast. The method takes into account processes of blur, noise, and image correlations, to make an optimal estimate of the missing pixels. The theory is briefly described and experiments are reported.

8.2.1-7 Friday November 1, 16h30-16h45
International Standardisation in Medical Thermography - Draft Proposal

R.P. Clark and M.L. de Calcina-Goff University of London, King's College London

Abstract Within the world-wide community of medical thermographers there is general agreement that standardisation in a number of aspects of thermography is both desirable and necessary if meaningful comparison of results between centres is to be achieved. This paper outlines the proposals for a draft Standard for medical thermography that will cover aspects of thermographic terminology, technique and application/interpretation of thermal images.

8.2.2: IR Imaging in Medicine II - Quantitative Clinical Applications - chair: Nicolas Diakides & W.E. Snyder [Orals]

8.2.2-1 Saturday November 2, 15h00-15h15
Development of a Database for Medical Infrared Imaging

I. Fujimasa, T. Chinzei and K. Mabuchi Saitama University

The object of the report is to describe concepts and methodologies for developing a database of medical infrared thermography. The infrared thermography is a typical non-invasive imaging modality to express thermal homeostatic functions of a body which include skin blood flow distribution and autonomic nerve functions. However physiological functions such as skin surface temperature are easily and rapidly modified many in- and extrinsic factors. If there are no standards or guidelines to handling the thermographs, a clinician sometimes misreads pathophysiological meanings of his patient from infrared images. This is a system to supply standard techniques of handling infrared imaging modalities and to draw up guidelines for diagnosing some pathophysiological status using thermographic images through Internet system.

8.2.2-2 Saturday November 2, 15h15-15h30
Application of Second Generation Infrared Imaging with Computerized Image Analysis to Breast Cancer Risk Assessment

J.F. Head, C.A. Lipari, F. Wang, J.E. Davidson and R.L. Elliott Medical Thermal Diagnostics

ABSTRACT Infrared imaging of the breast for breast cancer risk assessment with a second generation focal plane staring array system was found to produce images superior to a first generation scanning system. The second generation system had greater thermal sensitivity, more elements in the image and greater dynamic range, which resulted in a greater ability to demonstrate asymmetric heat patterns in the breasts of women being screened for breast cancer. The improved imaging of the second generation infrared system allowed more objective and quantitative visual analysis, compared to the very subjective qualitative results of the first generation infrared system. The greater sensitivity and resolution of the digitized images of the second generation infrared system also allowed image analysis of total breasts, breast quadrants and hot spots to produce mean, standard deviation, median, minimum and maximum temperatures =

8.2.2-3 Saturday November 2, 15h30-15h45
Non-Invasive Imaging in the Investigation of Deep Vein Thrombosis in Pregnancy

J.R. Harding and A.M. Wright Royal Gwent Hospital, Consultant Radiologist

Deep vein thrombosis (DVT) is a serious condition which can be complicated by the development of pulmonary embolism, which has a high mortality and morbidity. There is an increased incidence of deep vein thrombosis in pregnant patients. Effective treatment of DVT by anticoagulation dramatically decreases the risk of pulmonary embolism, but poses risks of its own, particularly in pregnancy, and should not be undertaken without a confirmed diagnosis. Thermal imaging is quick, simple, non-invasive, risk-free, cost-effective and highly sensitive in the initial investigation of suspected DVT; a negative thermogram excludes DVT and avoids the necessity for further investigation. Thermal imaging is, however, non-specific; a positive thermogram has a number of possible causes and is an indication for further assessment by venography or Doppler ultrasound to confirm or exclude DVT. Thermography should be considered the initial investigation of choice in clinically suspected DVT in pregnancy, proceeding to venography or Doppler ultrasound only when thermography is positive.=

8.2.2-4 Saturday November 2, 15h45-16h00
Infra Red Thermal Imaging of the Skin Quantifies Reactive Hyperaemia

E.F.J. Ring and D. Elvins Royal Nat. Hospital for Rheumatic Diseases

Infra Red Thermal Imaging is a highly developed procedure for mapping skin temperature distribution. It is possible to induce local skin blood flow changes by chemical, radiation and thermal stress to the skin. Localised trauma from mechanical stress can also be measured by this technique from a two dimensional dynamic image. Examples of experimental U.V.erythema, topical vasodilator, and cold stress reaction to the hands are described. In the latter case an index of vasospasticity can be calculated in Raynauds Phenomenon, and reactive hyperaemia may be induced in normal hands.

8.2.2-5 Saturday November 2, 16h00-16h15
Digital Dual Band Infrared Imaging in Assessment of Nitrogen Mustard Injury in Skin

K. Zamani, N. del Grande, M. Bonner and M. Marino Walter Reed Army Institute of Research

Digital Dual-Band Infrared Imaging (DDBII) is a non invasive technique for speedy examinations of skin contamination/injury due to mustard exposure. In preliminary studies, live pig skin was exposed to nitrogen mustard (HN2) which was used as a surrogate agent for sulfur mustard. Thirty minute exposures of pig skin to HN2 produced visible erythema after a couple of hours, while the vehicle only (ethanol) treated spots remained unchanged. On the other hand, DDBII examination of the agent and vehicle treated spots, starting at 20 minutes with follow up readings at 1.5, 3, 6 and 22 hours post exposure, revealed a general cooling of the HN2 treated areas. At 22 hours a transient heat stress challenge failed to produce the expected normal flush in HN2 treated areas, indicating a possible lack of sympathetic response, the mechanism of which needs to be elucidated. DDBII was able to detect mustard contamination/injury prior to the clinical manifestations. This makes DDBII a promising technique for evaluating the efficacy of prophylactic drug candidates for mustards. DDBII also has the potential for use in evaluation of exposure to mustards in the field with on-site or remote, real time evaluations.

8.2.2-6 Saturday November 2, 16h15-16h30
Applications of Fourier Transform Infrared Imaging Microscopy in Histopathology

D.S. Lester, L.H. Kidder, I.W. Levin, V.F. Kalasinski and E.N. Lewis Food and Drug Administration

Infrared microspectroscopic imaging has the capabilities of generating spatial information as well as the standard spectroscopy. By taking advantage of the vibrational spectral signatures of biological components, such as lipids and proteins, we have the capability of obtaining images of the intrinsic distribution of these molecules. We have applied this approach to analyze tissue sections of biomedical relevance in order to determine the potential of this application as an alternate approach to histopathology. The advantage of this technique is that tissue need not be fixed or stained, contrast obtained from the intrinsic distribution of the biomolecular components. This technique provides considerable application for many histopathological applications and could result in the significant increase in the speed and resolution of pathological analyses, such as biopsies.

8.2.3: IR Imaging in Medicine III-Clinical Applications and Technology Transfer - chair: G.Hammer & M.Hopmeier [Orals]

8.2.3-1 Sunday November 3, 09h00-09h15
Thermal Endoscopic Systems and Their Applications in the Biomedical Field

K. Mabuchi, T. Chinzei and I. Fujimasa The University of Tokyo

Thermal endoscopic systems could provide not only useful information concerning abnormalities in spaces within tubular tissues or inside the body, but could also have other applications such as in emergency rescue situations. This project examined the possibility of developing endoscopic systems to produce thermal images using fibers and their bundles which can transmit infrared (IR) light, and investigated the feasibility of such systems. Although it was possible to identify and observe the organs inside a subject's oral cavity and the viscella of experimental animals through the fiber bundle, the transmitted quality of the thermal images is still not good enough for diagnostic purposes. However, recent advances in infrared light detectors, the development of new materials for IR fibers, and improvements in the IR electronic endoscopic system should lead to the development of endoscopic systems for thermal images with the required temperature resolution in the near future.

8.2.3-2 Sunday November 3, 09h15-09h30
Near Infrared CCD Imaging of Hemondynamics

H.O. Such Aachen University of Technology

This paper presents preliminary results of near infrared CCD imaging of hemodynamics with inexpensive system components. The motivation behind this is the requirement of a low-cost and easy to use system capable of aiding the physician in daily assessment of venous disorders such as chronic vein insufficiency (CVI) and deep vein thrombosis (DVT). Photoplethysmographic (PPG) systems with optical sensors are in wide use for these tests today. They essentially measure the blood volume in the top skin layers. Another method that has been described for imaging of veins is near infrared photography. The presented method combines the two. A monochrome CCD camera equipped with a >700nm filter is mounted on a tripod. A constant indirect illumination is applied, then an exercise is performed by the patient. The camera takes a sequence of pictures of the perfusion area of interest, i.e the lower leg. Digital filtering and sequence evaluation results in image-mapped data about venous reflow time, venous pump power and other relevant parameters From this, conclusions can be taken as to the reason and location of disorders

8.2.3-3 Sunday November 3, 09h30-09h45
Study of Near Infrared Imaging of a Model of Brain Edema

L. Johnson, N. Thakor and D. Hanley John Hopkins University School of Medicine

ABSTRACT Currently, methods for the detection of brain edema in patients or laboratory experiments are not ideal. MRI does not permit time resolution of injury and intracranial pressure monitoring is invasive. We have performed experiments on a model of brain edema to examine near infrared imaging as a convenient, low cost and noninvasive method of monitoring brain edema. We prepared an in vitro model of edema consisting of serial dilutions of Intralipid(, a fat emulsion, to simulate varying degrees of brain water content. NIR light at two wavelengths (920 nm and 980nm) was used to assess the water content of Intralipid(We obtained a correlation coefficient of 0.98 between water content and NIR absorption difference We used the CCD system to image a model with spatial variations in water content Our preliminary results suggest NIR spectroscopy as a useful technique for monitoring brain edema in both clinical and laboratory settings

8.2.3-4 Sunday November 3, 09h45-10h00
A Real-Time 3D Ultrasonic Imager Based on a 128 x 128 Transducer Array

T. White, K. Erikson and A. Nicoli Lockheed Martin IR Imaging Systems

Real-time 3D ultrasound imaging has the potential for making dramatic improvements in medical imaging applications. Until recently, fabrication difficulties have limited even the most advanced 3D ultrasound systems to mechanically scanned 1D or 1.5 D linear arrays together with off-line reconstruction, or 2D arrays with a limited number of displayed real-time planes. Fabrication of a real-time volumetric imaging system requires a large number and high density of array elements and the interconnections to the associated electronics. Lockheed Martin has developed a 42 X 64 (2688 total) element 5 MHz 2D array, hybridized to a custom CMOS integrated circuit. Results to date have demonstrated bistatic real-time imaging with three dimensional resolution of 1mm in a tissue equivalent test object. In this paper, we describe our work-in-progress with a 128 X 128 (16,384 total) element array and 3D real-time imaging system Through massively parallel, focal plane processing, the goal of real-time 3D ultrasonic imaging in the low MHz frequency is now achievable.

8.2.3-5 Sunday November 3, 10h00-10h15
NASA's Technology Transfer Program for the Early Detection of Breast Cancer

G.K. Schmidt, M.A. Frey and J. Vernikos NASA

The National Aeronautics and Space Administration (NASA) has led the development of advanced imaging sensors and image processing technologies for space science and Earth science missions. NASA considers the transfer and commercialization of such technologies a fundamental mission of the agency. Over the last two years, efforts have been focused on the application of aerospace imaging and computing to the field of diagnostic imaging, specifically to breast cancer imaging. These technology transfer efforts offer significant promise in helping in the national public health priority of the early detection of breast cancer

8.2.3-6 Sunday November 3, 10h15-10h30
Long Term Performance Evaluation of an Automatic Airway Positive Pressure Device

F-C. Yen, K. Behbehani, J.R. Burk, E.A. Lucas and J. Axe University of Texas at Arlington

Long term studies of automatic continuous positive airway pressure (Auto CPAP or APAP) device is presented. APAP device is designed to eliminate OSA events automatically. It detects pharyngeal wall vibration (PWV) signal and uses it as feedback signal to adjust airway pressure. Two positively diagnosed obstructive sleep apnea patients participated in this study. A computer-based data acquisition system was used to collect the APAP pressure signal during the sleeping hours Pressure trends for 182 nights for the first patient and 260 nights for the second patient were obtained. Both patients reported satisfaction with the APAP therapy The pressure trends obtained from these two subjects revealed that the pressure level required for eliminating PWV changes though out the night and from night to night as well as the mean APAP pressure level was significant lower than the CPAP prescribed pressure (1st subject: 3.2 cmH2O of mean APAP pressure vs. 7 cmH2O of CPAP prescribed pressure, 2nd subject 3.7 cmH2O of mean APAP pressure vs. 15 cmH2O of CPAP prescribed pressure). Therefore, adjusting the blower pressure automatically based on PWV signal detection may provide comparable treatment to that of conventional CPAP device with lower airway pressure.

8.2.3-7 Sunday November 3, 10h30-10h45
DTIC - Your Information Source for New Technologies and Applications

C.M. Cupp Defence Technical Information Center

As the central component of the Department of Defense's Scientific and Technical Information Program (STIP), the Defense Technical Information Center (DTIC) contributes to the management and conduct of defense research, development and acquisition efforts by providing access to and transfer of scientific, technical, and management information for DoD personnel, DoD contractors and potential contractors, and other U.S. government personnel and their contractors Transferring information about current knowledge such as new bioengineering developments with inertial loading effecting helmet mounted devices, robotics, functional characterization of odorant receptors, etc., is vitally important to the creation of new knowledge. Now that the cold war is over, U.S. defense resources have been reduced accordingly We must increasingly turn to commercial or commercially derived products for our needs, taking advantage of both economies of scale and of cutting edge technologies that are found in the private sector The products and services offered by DTIC provide an invaluable source of information to both the government and contractor communities in their efforts to identify and develop dual use technologies. Such products and services include active participation in the Small Business Innovative Research Program (SBIR) solicitations; management of a domestic technology research database, access to more than 1,000 commercial and government databases; Internet service via public access gophers, web clients, WAIS, Listservers, etc.; Manage information analysis centers which help defense scientists and engineers and their contractors find, analyze and use scientific and technical information; and access to more than two million technical reports and summaries of works in progress.

MINISYMPOSIA:

M1: Emerging Technologies for Clinical Bone Assessment (Jonathan J. Kaufman)

M1-1
Ultrasonic Assessment of Bone

A.E. Chiabrera University di Genova

This talk will provide a broad overview of the use of ultrasonic methods for noninvasive assessment of bone First a brief introduction to the physical principles involved in ultrasonic methods will be given. Next, a review of the published literature on ultrasonic bone assessment, including theoretical, in vitro and clinical data will be presented. A description of recent developments will also be provided, including results using a new clinical ultrasonic system and a new set of ultrasonic parameters. Finally, an extensive set of references is included for further inquiry

M1-2
Analysis of Trabecular Bone Texture on Radiographs

Final Program & Abstract Book

19th Annual International Conference of the IEEE Engineering in Medicine and Biology Society

Oct. 30 - Nov. 2, 1997
Chicago IL USA

"Magnificent Milestones and Emerging Opportunities in Medical Engineering"

EMB

IEEE

Session 2.5.1: Quantitative Clinical IR Imaging-I Thursday, October 30, 4:30-6:00pm, Salon B

2.5.1-a Infrared Thermography for Control of Hemodialysis Shunts

T. Maca, S. Schmaldienst, M. Atteneder, S. Fasching, W. Horl, R. Katzenschlager, E. Knespel, I. Koppensteiner, R. Koppensteiner, A. Ugurluoglu, A. Willfort, H. Ehringer - University of Vienna, AUSTRIA

Hemodialysis through an arteriovenous (AV-) fistula remains the most frequent treatment of terminal renal insufficiency until renal transplantation. In case of malfunction of the shunt colour coded duplex sonography or angiography are used for investigation. We tried to evaluate the technical feasability of infrared thermography for control of hemodialysis shunts. 27 consecutive patients who were planned for duplex sonographic control of their AV-shunts had temperature measurements by infrared thermography before dialysis. All investigations were done under standardized ambient conditions with an Infrared Thermo Tracer TH1100. Morphological and functional aspects of AV-fistulas have been compared with their digitized infrared thermograms. The maximal shunt flow velocity (m/sec) correlated best with the highest temperature difference between arms ($p < 0.001$). The shunt-volume proved to be significantly correlated with the mean temperature difference to the contralateral upper extremity ($p < 0.05$). Patients suffering a complete thrombosis of their shunt (n=4) presented statistically lower maximum temperatures on the surface of their shunt regions (33.9 ± 1.0 C) than AV-fistulas without occlusion (36.3 ± 0.6 C), $p < 0.01$. Our data seem promising that infrared thermography might deliver additional fast and non-invasive global information of function of hemodialysis shunts.

2.5.1-b The Role of Infrared Thermography in Diagnosis and Management of Pain

H. Hooshmand - Neurological Associates Pain Management Center, Vero Beach, USA

Infrared Thermal Imaging has been utilized in medicine for diagnosis of conditions such as peripheral and central vascular disease, breast cancer, and a variety of painful conditions such as neuropathic pain and nerve root disorders. The following text addresses the role of thermal imaging in the diagnosis and management of pain. The Infrared Thermography (TG) cannot be exclusively diagnostic of a specific disease, but provides important diagnostic information only limited to the thermal function of the sympathetic system. As such it can be utilized as both a diagnostic tool and a guide in application of treatment modalities. This paper is a review of applications of the (TG) in management of chronic pain.

2.5.1-c Thermal IR Imaging in Trauma

W. Snyder - North Carolina State University, USA, E. Schwartz - North Carolina Baptist Hospital, USA, G. Snyder - University of North Carolina at Chapel Hill, USA

An initial evaluation of the applicability of thermal IR imaging to trauma patients was performed at North Carolina Baptist Hospital. Patients were imaged using two cameras, one in the mid-wave and one in the long-wave IR. Results indicated that IR could serve to detect perfusion abnormalities by distal-proximal comparison and by left-right comparison.

2.5.1-d Study of the Thermal Differences on the Meridian Points Used to the Cold Hypersensitivity

K-S. Lee - Kyung Hee University, KOREA, Y. Kim - Yonsei University, KOREA

The acupuncture treatment is using the acupuncture, a needle made of various metals. These acupunctures are injected to the meridian acupuncture points according to the meridian theory and give an adequate stimulus to the body. This makes the control of the movements of the Qi, so that it induces the purpose of treatment, and prevention of diseases. Cold hypersensitivity is the feeling cold when one should not feel cold. This is a disease causing many difficulties in normal life to the patients, but until now the cause of the cold hypersensitivity is not known. The object of this study is the evaluation of the thermal differences on the meridian points in the cold hypersensitivity. When the patients appealed cold feeling, we diagnosed the cold hypersensitivity by the D.I.T.I.. After we acupunctured the patients, took again the D.I.T.I., then we observed the differences between them. Thereafter we acupunctured the patients 3 times for a week, and before and after the 3rd treatment, we took the D.I.T.I.. To evaluate the differences of the meridian points, we used the thermal deviation of the D.I.T.I. According to this study, 56% of all the cases showed thermal increase on average. The gradual decreases of thermal deviation maybe resulted from the increase of the average body temperature. About this difference of the thermal distributions between extremities, further study may be required.

2.5.1-e Mapped Hemodynamic Data Aquisition by Near Infrared CCD Imaging

O. Such, S. Acker, V. Blazek - Aachen University of Technology, GERMANY

This paper presents undergoing research results of a near infrared CCD imaging system designed for mapped aquisition of hemodynamics data with inexpensive system components. This system is intended for use by clinicians and in phebological practice. The tests that can currently be done with this system are the classical Muscle Pump Test (MPT) and the Vein Occlusion Test (VOT). These are standard tests for venous disorders such as chronic vein insufficiency (CVI) and deep vein thrombosis (DVT).

2.5.1-f Biomedical Infrared Imaging in Japan: Present Status and Future Strategies

B. Harrison - Chuo University, JAPAN, K. Mabuchi - The University of Tokyo, JAPAN

This paper discusses the professional and cultural preconceptions that may exist in collaborative work involving researchers from many nations and disciplines; difficulties faced by Japanese researchers; specific points pertaining to increasing the participation of Japanese in international projects on biomedical infrared imaging; the composition of the Japanese Society of Thermology; the imaging systems currently employed in Japan, and the extent of their use; and the difficulties that must be overcome in order to achieve wider adoption of infrared imaging techniques in Japan.

Session 2.5.2: Quantitative Clinical IR Imaging-II

Friday, October 31, 8:30-10:00am, Salon B

2.5.2-a Study of Skin Hemodynamics with Fast Dynamic Area Telethermometry (DAT)

M. Anbar, L. Milescu - SUNY at Buffalo, USA, M. Grenn - US Army CECOM NVESD, Fort Belvoir, USA, K. Zamani, M. Marino - Walter Reed Army Institute of Research, USA

Dynamic area telethermometry (DAT) is a highly useful in the study of the physiology or pathophysiology of the vascular system and its neuronal control. DAT entails acquisition of hundreds of consecutive infrared images, facilitating the quantitative analysis of the modulation of cutaneous temperature and of its spatial homogeneity. This analysis, which characterize the dynamics of skin perfusion, allows the assessment of local and systemic hemodynamics by a fast, inexpensive, non-contact procedure. DAT can be applied in different time frames, analyzing fast and relatively slower neuro-vascular hemodynamic processes.

depending on the rate of data acquisition. In this paper we describe the application of fast DAT to monitor the effect of the dynamics of the cardiac cycle on the perfusion of the peripheral skin. Using a 256x256 FPA Ga/As quantum well infrared photodetector (QWIP) camera at a rate of 66 frames per second, we monitored hemodynamic processes which modulate peripheral skin temperature 10 to 50 millidegrees. We have shown that while the size of the sampled area is not critical for the interpretation of hemodynamic processes, studying the thermal dynamics of a cluster of many small areas allows to determine the directionality of cutaneous blood flow.

2.5.2-b Is DVT Excluded by Normal Thermal Imaging? - An Outcome Study of 700 Cases

J. Harding, K. Barnes - St Woolos Hospital, Gwent, UK

Untreated deep vein thrombosis (DVT) has a significant morbidity and mortality as it can cause pulmonary embolism (PE). This risk is substantially eliminated by effective anticoagulation, which prevents further thrombus formation in the leg veins, allowing gradual natural absorption of the existing blood clot, but this treatment has risks of its own and is not indicated without a definite diagnosis. Clinical diagnosis is extremely misleading, so accurate clinical tests are required to rule out or rule in clinically suspected DVT. There are risks and disadvantages to the most commonly utilised conventional tests for DVT, over one third of which examinations can be avoided by performing thermal imaging as the initial investigation, which excludes DVT when normal. This outcome study followed up patients with clinically suspected DVT who were not further investigated or treated following normal thermal imaging, and showed that no patients developed PE following normal thermography with no further investigation for DVT and withholding of anticoagulant therapy.

2.5.2-c Far Infrared Medical Image Database on World Wide Web

I. Fujimasa - National Graduate Institute for Policy Studies, JAPAN, I. Saito, T. Chinzei - University of Tokyo, JAPAN

In order to set up the international standards for medical infrared thermography we have been developing an international communication tool on World Wide Web (WWW) named Biomedical Thermology Homepage (http://biomed.poli-sci.saitama-u.ac.jp/bmth/). The methodology and system concept have been reported in last year [1]. In this report, the concept and methodology of the image database named Gallery were reported. The keynotes are how we establish remote access of image handling software to analyze common source binary images in the database. We have been developed software which were written with Visual Basic and JAVA. The system, which has included more than 20,000 binary images, has been tested its feasibleness from remote site.

2.5.2-d A Database of Archival Infrared Thermal Imaging in Medicine Papers

B. Jones - University of Glamorgan, UK, E. Ring - Royal National Hospital for Rheumatic Diseases, Bath, UK

Infrared thermal imaging has been applied in medical research since 1960 in several research centres in Europe, the USA and Japan. Many papers were published in the journals ACTA THERMOGRAPHICA and the Journal of Thermography. During this period, several important basic principles of thermal imaging were established, such as the thermal symmetry inherent in a healthy subject. Both journals ceased publication some years ago and the material is not readily available for reference. The US National Technology Transfer Center has agreed to fund the production of a CD ROM to make this material widely available for researchers in medical thermal imaging. Some information will also be disseminated by the World Wide Web. It is important to avoid 're-inventing the wheel' during the resurgence of interest in thermal imaging prompted by the availability of the advanced infrared cameras that have been developed by the US military over the last twenty years.

2.5.2-e Measurement of Regional Oxidative Metabolism in Muscle using Near-Infrared Spectroscopy

E. Nakagawa, H. Minamitani, R. Ochiai - Keio University, JAPAN, H. Yamamura - TOSTEC Co., Ltd., JAPAN

Blood flow and oxygen supply to skeletal muscle is a potentially important factor to maintain muscular oxygenation metabolism. In clinical usage, a well-functioned noninvasive system for measuring the muscular blood flow and metabolism is needed. Recently, near-infrared spectroscopy (NIRS) has been developed and become a useful technique for noninvasive monitoring of the regional oxygen supply. From this point of view, we proposed a new system to monitor and evaluate the regional oxygen saturation rSO2 and volume of hemoglobin using hemoglobin index (HbI) more simply and inexpensively for clinical application. The aim of this study is to estimate the oxygen metabolism in human muscles during physical exercise by using NIRS system and cycle ergometry.

2.5.2-f Methods in Near-Infrared Photon Migration Tomography

A. Hielscher - Los Alamos National Laboratory, USA

The basic methods used in near-infrared photon migration tomography ae reviewed. This includes technical equipment design and reconstruction algorithm. Special emphasize is placed on model-based iterative reconstruction methods.

Session 2.5.3: IR Imaging in Breast Cancer
Friday October 31, 10:30am-12:00pm, Salon B

2.5.3-a The Contribution of Currently Available High Resolution Infra-Red Imaging to the Detection of Stage I and II Breast Cancer

J. Keyserlingk, P. Ahlgren, E. Yu, N. Belliveau - St. Mary's Hospital Center, Montreal, CANADA

By the late sixties, combined studies proposed that both the sensitivity and specificity of infrared imaging of the breast was approximately 85%. This data justified it's introduction into the Breast Cancer Detection Demonstration Project. The initial enthusiasm for this technique rapidly waned in North America. The Ville Marie Breast Center has continued to use this technique as a component of our multi-modality imaging strategy in the detection of breast cancer. The recent acquisition of high resolution digital infrared technology along with the development of a standard protocol for image production and interpretation by qualified physicians has given us an opportunity to better assess it's complimentary role to clinical exam and mammography. In a recent series of early breast cancer patients, the combined use of both infrared imaging and mammography was particularly useful in the patients in whom mammography, though done in a fully accredited center, was uninformative. Adding infrared imaging to mammography increased the detection rate. When infrared imaging benefits from the same quality control recently imposed on mammography, it constitutes a safe and practical imaging modality that in some cases promoted an earlier detection of breast cancer than did mammography.

2.5.3-b Some Considerations on the Diagnosis of Breast Cancer by Thermography in Patients with Nonpalpable Breast Cancer

Y. Ohashi, I. Uchida - Cancer Institute Hospital, JAPAN

Twenty-six patients with nonpalpable breast cancer were examined by thermography. 15 patients (55%) were correctly diagnosed by thermography at steady state, 4 patients (14%) were correcdy diagnosed by the aid of dynamic thermography and 3 patients (11%) were correctly diagnosed by the aid of μ-thermography.

Background of diagnosis of small cancer by thermography at steady state as well as dynamic and υ-thermography was studied.

2.5.3-c Advanced Infrared Image Processing for Breast Cancer Risk Assessment

C. Lipari - Arizona State University-East, USA, J. Head - Elliot Mastology Center, USA

The following report describes image processing techniques applied to high resolution breast thermograms as used to predict breast cancer. The goal is to observe asymmetry in the heat pattern due to temperature differences and/or the areas of observed vesicular structure and other "hot spots". Temperature and hot spot area differences are computed between the patient's left and right breasts and structurally matched breast quadrants. The approach is designed to generate objective measures for determining the patient's cancer risk.

2.5.3-d Infra-Red Imaging in Breast Cancer

P. Gamagami, M. Silverstein, J. Waisman - The Breast Center, Van Nuys, USA

In 1982, inspired by the notion of angiogenesis in experimentally transplanted cancer in animals showing that a small transplanted cancer could not "take" in the recipient organ unless tumor angiogenesis was established. We undertook a clinical research in 530 breast cancer patients who had previous mammography to see whether angiogenesis could be seen on mammography in early breast cancer and if so, could it have any impact on the detection of early breast cancer. Furthermore, we studied angiogenesis by infra-red imaging camera in a large number of symptomatic and asymptomatic patients, in 148 non-palpable cancers and in 20 inflammatory breast carcinomas. We found the following: Angiogenesis was the first sign appearing on mammography before the appearance of image of breast cancer, predicting in 91% of the cases which breast might develop breast carcinoma. This is an important finding in the detection of the early stages of breast cancer development. Infra-red imaging goes hand in hand with mammography. Hypervascularity and hyperthermia could be shown in 86% of non-palpable breast cancer. In 15% it helped to detect the cancer upon an unsuspicious image on mammography. Infra-red imaging was found to be the only test showing the efficiency of chemotherapy in inflammatory breast carcinoma.

2.5.3-e Image Analysis of Digitized Infrared Images of the Breasts from a First Generation Infrared Imaging System

J. Head, C. Lipari, F. Wang, R. Elliott - Medical Thermal Diagnostics, USA

Infrared imaging, often called thermography in medicine, of the breasts has been shown to be of value in risk assessment, detection, diagnosis and prognosis of breast cancer. However, infrared imaging has not been widely accepted for a variety of reasons, including the lack of standardization of the subjective visual analysis method. The subjective nature of the standard analysis makes it difficult to achieve equivalent results with different equipment and different interpreters of the infrared patterns of the breasts. Therefore, this study was undertaken to develop more objective methods of analysis of infrared images of the breasts by creating objective semiquantitative and quantitative analysis of computer assisted image analysis determined mean temperatures of whole breasts and quadrants of the breasts. When using objective quantitative data on whole breasts (comparing differences in means of left and right breasts), semiquantitative data on quadrants of the breast (determining an index by summation of scores for each quadrant), or summation of quantitative data on quadrants of the breasts there was a decrease in the number of abnormal patterns (positives) in patients being screen for breast cancer and an increases in the number of true positives in the breast cancer patients. It is hoped that the decrease in positives in women being screened for breast cancer will translate into a decrease in the false positives but larger numbers of women with longer follow-up will be needed to clarify this. Also a much larger group of breast cancer patients will need to be studied in order to see if there is a true increase in the percentage of breast cancer patients presenting with abnormal infrared images of the breast with these objective image analysis methods.

2.5.3-f Dye-Enhanced Multispectral Transillumination for Breast Cancer Detection: Feasibility Measurements

M. Braunstein, R. Chan, R. Levine - MIT Lincoln Laboratory, USA

Near-IR transillumination for breast cancer detection is limited by poor discrimination among different breast conditions; including the presense of cancerous, benign, and fibrous tissues. Perhaps due to enhanced vascularity, there is evidence that a contrast agent, indocyanine green (ICG), accumulates at the site of malignant tumors. The 805nm absorption edge of the compound suggests that multispectral transillumination, coupled with special-purpose data fusion processing, could enhance the discrimination of tumors. In this paper we report on the transillumination of in-vitro tissue samples in which minute (< 10 υ gm quantities of ICG have been injected. Discrimination and deblurring algorithms fusing multispectral images in the range 750nm - 1000nm are applied to enhance detectability of the ICG in tissue.

Session 2.5.4: Hyperspectral Imaging in Medicine

Friday October 31, 4:30-6:00pm, Salon B

2.5.4-a Infrared Spectroscopic Imaging Using Focal-Plane Arrays: Applications to Tissue Analysis and Histopathology

L. Kidder, I. Levin, E. Lewis - National Institute of Diabetes and Digestive and Kidney Diseases, NIH, USA

Infrared imaging spectroscopy has been used to investigate several biological systems. The imaging instrument is comprised of IR sensitive array detectors coupled with a step-scan interferometer and microscope. Each pixel on the array simultaneously measures an IR spectrum in frequency ranges that depend only on the type of array employed. As image contrast is provided solely by spatial variations in a sample's intrinsic chemistry, this technique enables researchers and clinicians to visualize a sample directly in terms of its chemical heterogeneities. We illustrate the capability and versatility of this technique for readily and non-invasively visualizing chemical complexity and for providing statistical data on sample heterogeneity. FT-IR spectroscopic imaging provides the means to better understand the molecular composition and architecture of biological materials, as well the ability to probe the biochemistry of diseased tissue states.

2.5.4-b FT-IR Chemical Imaging of Biomineralized Tissue using a Mercury-Cadmium-Telluride Focal-Plane Array Detection

C. Marcott, R. Reeder - The Proctor and Gamble Company, USA, E. Paschelis, A. Boskey - The Hospital for Special Surgery and Cornell Medical School, USA, R. Mendelsohn - Rutgers University, USA

A 64 x 64 Mercury-Cadmium-Telluride (MCT) focal-plane array detector attached to an FT-IR microscope was used to spectroscopically image 5-micron slices of human bone tissue in the fingerprint region of the infrared spectrum. The protein, carbonate, and phosphate concentrations change as function of distance from an osteon. Changes in the phosphate IR band shapes also occur, suggesting a spatial dependence to the biomineralization process.

2.5.4-c Assessment of a Laser-Powered Multiwavelength Near-Infrared Spectrometer

A. Martinez-Coll, P. Cooper - Royal North Shore Hospital, AUSTRALIA, G. Murphy, H. Nguyen - University of Technology, AUSTRALIA

Abstract Near infrared spectroscopy is a non-invasive technique for measuring relative blood volume and oxygen saturation in tissue. We have designed and built a research NIR-spectrometer which offers the flexibility to study changes in blood oxygen saturation (SO_2) and in blood volume (BV) during skeletal muscle pacing. The instrument consists of five 1 watt solid state lasers (780, 800, 830, 850 and 980 nm) fired sequentially at 5μs pulses for a 1ms cycle, and a 5 mm^2 photodiode receiver. Features of the spectrometer include, rapid realtime data acquisition (1000 samples/s), receiver protection against ambient light, large dynamic optical power output adjustable for each wavelength, and portability. In vitro photon scattering experiments and linear response to blood oxygen saturation changes for differential absorption (780 - 850 nm) provide an accurate measure of changes in SO_2, while the 800 nm signal can be used as a measure of blood volume change independently of SO_2 (±2%- SO_2 error). In addition, the 980 nm signal level is explored as an index of mean pathlength which may provide crucial information for determining absolute SO_2.

2.5.4-d Multispectral and Hyperspectral Imaging: Applications for Medical Diagnostics

J. Freeman - Surgical Imaging, Inc., USA, F. Downs - Coastal Systems Station, USA, L. Marucci - Surgical Imaging, Inc., USA, E. Lewis -NIH, USA, B. Blume - Nichols Research Corporation, USA, J. Rish - Coastal Systems Station, USA

One of the keys to a surgeon's successful work is his or her ability to see and feel well enough to adequately identify problems, particularly those that were not anticipated. Thus, an extension of the surgeon's vision would be a significant breakthrough. Multispectral and hyperspectral imaging techniques, along with associated algorithms and image processing methodologies have been developed by the military for detecting, classifying and identifying targets amid background clutter. Applying this technology to medicine will allow novel exploration of anatomy, physiology, and pathology.

2.5.4-e Acousto-Optic Sensing and Imaging for Biomedical Applications

N. Gupta, R. Dahmani - Army Research Laboratory, USA

Recent advances in acousto-optic tunable filter (AOTF) technology and signal processing algorithms implemented therein offer the potential for designing instruments with computer- controlled, rapid, frequency-agile tuning over a large optical wavelength range. We are testing a number of AOTF spectrometers and cells in our laboratory for application in remote sensing and imaging of chemical and biological agents using absorption, fluorescence, and Raman spectroscopic techniques. In particular, an imaging experiment is described that is being set up in our laboratory using one of the two AOTF cells: a low-resolution visible cell (400-900 nm) and a high resolution UV-Visible cell (255-800 nm). The details of this experiment and the AOTF cells are presented.

2.5.4-f An Algorithm that Estimates Background Lumiphore for Luminescence Optical Tomography

J. Chang, H. Graber, R. Barbour - SUNY Health Science Center at Brooklyn, USA

We examine the impact of background lumiphore on image quality in luminescence optical tomography. A modification of a previously described algorithm [1,2] is developed that estimates the background luminescence directly from the detector readings. Numerical simulations were performed to calculate the diffusion-regime limiting form of forward-problem solutions for a specific test medium. Image reconstructions were performed with and without white noise added to the detector readings, using both the original and the improved versions of the algorithm. The results indicate that the original version produces unsatisfactory reconstructions when background lumiphore is present, while the improved algorithm yields qualitatively better images, especially for small target-to-background lumiphore ratios.

Session 2.5.5: IR Systems and Image Processing
Saturday, November 1, 4:30-6:00pm, Salon B

2.5.5-a Performance of Portable Staring Infrared Cameras

M. Grenn - US Army CERDEC Night Vision and Electronic Sensors Directorate, USA

The availability of high quality MWIR and LWIR staring infrared focal plane arrays (IRFPAs) has enabled system manufacturers to develop portable imaging systems with thermal resolution less than .020 Kelvin at standard video frame rates. These staring IRFPA systems exceed the performance of portable serially scanned systems used in medical studies prior to mid 1980 by more than a factor of 10. High quantum efficiency staring IRFPAs maintain sensitivity over narrow spectral bandwidths and at high frame rates, enabling the development of portable imaging spectrometers from the SWIR to the LWIR. The medical benefits of using high performance staring IRFPA systems for radiometric imaging, spectrally and temporally resolved imaging, and multisensor fusion have not been fully explored. A variety of portable packages are available from the industry, each containing unique design features that impact sensor performance, usability, size, weight, and power consumption. The performance of cooled and uncooled portable staring infrared cameras is presented, including temporal and spatial noise equivalent temperature difference (NETD), minimum resolvable temperature difference (MRTD), and stability.

2.5.5-b Portable Long-Wavelength Infrared Camera for Civilian Applications

S. Gunapala, T. Krabach, S. Bandara, J. Liu - Jet Propulsion Laboratory, USA

A 9 μm cutoff 256 x 256 hand-held quantum well infrared photodetector (QWIP) camera has been demonstrated. Excellent imagery, with a noise equivalent differential tempera-ture (NEΔT) of 26 mK has been achieved. In this paper, we discuss the performance of this portable long-wavelength infrared camera in quantum efficiency, NEΔT, minimum resolvable temperature difference (MRTD), uniformity, etc. and its civilian applications.

2.5.5-c Quantitative and Imaging Performance of Uncooled Microbolometer Sensors for Medical Applications

C. Marshall, T. Breen, M. Kohin, W. Watson, R. Murphy, N. Butler, T. Parker, L. Perich - Lockheed Martin IRIS, USA

Lockheed Martin IR Imaging Systems is developing low cost, high performance,uncooled infrared imaging products for both military and commercial applications. These products are based on the microbolometer technology, a silicon micromachined sensor that combines wafer level silicon processing with a device structure capable of yielding excellent imaging performance. Here we report on the latest technical improvements and performance of an uncooled sensor as measured through laboratory and field testing. The performance of our uncooled sensor has been measured to determine sensor capabilities for insertion into both military and commercial products. Linearity of the sensor over a scene temperature range of 95 °C is less than 0.5%. Our sensors typically have temporal NETDs of less than 70 mK as well as spatial NETDs of less than 50 mK. MRTD performance is less than 0.4 °C at spatial frequencies more than 20% beyond Nyquist. Sensor stability

over time has been measured and found to meet both commercial and military requirements. Spatial noise over a wide scene temperature range will be reported as well as other test results. Video will be used to demonstrate sensor performance capabilities in a variety of applications.

2.5.5-d A Head Mounted Infrared Imager for Treating the Wounded on the Battlefield

D. Luther, J. Davidson, R. Cromer, J. Head - Louisiana State University, USA

The use of a head mounted infrared imaging system for battlefield combat casualty care in total darkness without illuminating the wounded or the medic could greatly increase their survival rate. The head mounted unit will allow the visualization of the wounds in order to institute triage. The visualization of the wounds will allow treatment on the battlefield and allow evacuation of the more severely wounded first. The visualization of the blood vascular system in the skin and subcutaneous tissue will enable the medic to establish an intravenous route for blood, fluid, and drug therapy. The use of the unit will enable the medic to find the unconscious wounded on the battlefield so that treatment can be instituted. The survival rate of the wounded on the battlefield is significantly increased when treatment of the wounded are initiated within the first hour after the wound occurs. This head mounted infrared imaging system will allow for earlier treatment to be initiated in total darkness as well as in environments where smoke occludes visibility. Since the unit can be used without illuminating the wounded or the medic they will not become targets for the enemy which greater increases their safety.

2.5.5-e An Image-Processing Program for the Evaluation of Asymmetrical Thermal Distributions

K. Mabuchi, T. Chinzei - University of Tokyo, JAPAN, I. Fujimasa - Saitama University, JAPAN, S. Haeno, Y. Abe - University of Tokyo, JAPAN, T. Yonezawa - Osaka Medical College, JAPAN

The most common and most effective method for using thermography to detect abnormalities is to compare the thermographic image of the affected area with that of the corresponding contralateral healthy area, even though this method can be applied to cases with only hemilateral involvement. This paper describes the development of an image-processing program capable of producing images of the temperature difference between the affected side and the corresponding contralateral healthy side of the living body. The feasibility of the image-processing program was demonstrated by employing it for diagnostic purposes with actual clinical patients.

2.5.5-f Design of Near Infrared Reflectometer

R. Pasley - University of Memphis, USA, E. Wolf, H. Bada, C. Leffler - University of Tennessee at Memphis, USA, M. Daley - University of Memphis, USA

A two channel near infrared reflectometer was designed and fabricated using laser (814 nm and 751 nm) diodes and separate photodiode detector circuits. Because the isosbestic point of HbO2 and Hb is approximately 814 nm [1], the gains of each channel were equated at this wavelength. The device is designed to measure relative change of local cerebral blood volume, HbO2 and Hb concentration in an unknown sample volume.

Session 2.6.1: Image Technology Transfer
Sunday, November 2, 8:30-10:00am, Salon B

2.6.1-a Hybrid Detector Technology Applied to Digital Mammography

H. Roehrig - University of Arizona, USA, S. Gaalema, S. Dev Sharma, W. Yorke - Primex Corporation, USA

Hybrid detector technology based on indium metal bump-bonding techniques is under consideration for x-ray detection at x-ray energies of about 19.5 keV. Silicon of about 1 mm thickness forms the actual detector, converting x-rays directly into electrons (rather than generating light and converting light to photo-electrons). Time-delay-integration increases the sensitivity. Initial results demonstrate that a system based on this technology is useful as scanning x-ray detector for digital mammography and can meet and even exceed the performance of the conventional film/screen system.

2.6.1-b Simulation of Dye-Enhanced Near-IR Transillumination Imaging of Tumors

M. Braunstein, R. Chan, R. Levine - MIT Lincoln Laboratory, USA

Contrast agents with distinctive absorption and emission spectra, in combination with multispectral near-IR imaging, may provide a mechanism for the detection of breast cancer. While there is evidence of preferential drug accumulation at a tumor site, an important question is the concentration required to allow discrimination through tissue. An estimate of agent absorption effects is obtained from the solution of the diffusion equation in homogeneous tissue. In this paper absorption signatures derived from the diffusion equation and Monte Carlo simulation of a near-IR contrast agent, indocyanine green, are compared. Trade-off curves are generated among the key relevant parameters; contrast, depth, and agent concentration. It is also shown that the diffusion equation solution for a localized contrast agent leads to an algorithm to estimate tumor location and depth from near-IR images. The algorithm is applied to in-vitro IR measurements of a tissue sample with an injected contrast agent. The results have application to the design of contrast enhancing drugs and associated discrimination algorithms.

2.6.1-c Space Biosensor Systems: Implications for Technology Transfer

J. Hines, C. Somps, M. Madou - NASA - Ames Research Center, USA

To meet the need for continuous, automated monitoring of animal subjects, including humans, during space flight, NASA is developing advanced physiologic sensor and biotelemetry system technologies. The ability to continuously track basic physiological parameters, such as heart rate, blood pH, and body temperature, in untethered subjects in space is a challenging task. At NASA's Ames Research Center, where a key focus is gravitational biology research, engineers have teamed with life scientists to develop wireless sensor systems for automated physiologic monitoring of animal models as small as the rat. This technology is also being adapted, in collaboration with medical professionals, to meet human clinical monitoring needs both in space and on the ground. Thus, these advanced monitoring technologies have important dual-use functions; they meet space flight data collection requirements and constraints, while concurrently addressing a number of monitoring and data acquisition challenges on the ground in areas of clinical monitoring and biomedical research. Additional applications for these and related technologies are being sought and additional partnerships established that enhance development efforts, reduce costs and facilitate technology infusion between the public and private sectors. This paper describes technology transfer and co-development projects that have evolved out of NASA's miniaturized, implantable chemical sensor development efforts.

2.6.1-d Three-Dimensional Ultrasonic Imaging with a Fully Populated 128x128 Array

T. White, K. Eriksen, A. Nicoli - Lockheed Martin IRIS, USA

Survivability of combat casualties is driven by the ability of military medical personnel to rapidly assess the injury and take action. Prevention of exsanguination due to internal injury is greatly enhanced when diagnosis, triage and appropriate initial care can be delivered within the first hour. Increasing demands for improvements in casualty survivability requires the rapid diagnosis of blunt and penetrating trauma that only portable imaging modalities can provide. Ultrasound is the imaging modality with the greatest promise for portable use due to its low cost, compactness and real-time nature. Ultrasound provides definitive identification of blood pooling and internal organ integrity together with visualization of radiolucent foreign bodies. By creating a patient record that begins in the field, documenting and quantifying internal changes as the injury evolves, improved care can be realized. Lockheed Martin is developing a real-time three-dimensional ultrasound sensor system (3DUSS) to meet this emerging need based on a 128x128 array (Figure 1). This sensor, when coupled with appropriate PC-based processing and display electronics, forms an imager that is expected to meet the performance goals of: 15 Hz frame rate, 1 mm resolution, and greater than 30 dB of instantaneous dynamic range within a 90 dB total dynamic range.

2.6.1-e Acoustic Sensor Pad for Physiological Monitoring

M. Scanlon - Army Research Laboratory, USA

The Army Research Laboratory has developed an acoustic sensor pad technology that is useful for combat casualty care and soldier performance monitoring. Heartbeats, breaths, motion, and other physiological sounds relating to injured and uninjured soldiers can be detected, transmitted, and analyzed for diagnostic purposes. The acoustic sensor pad is a fluid-filled bladder with a hydrophone that couples well to the soldier's torso. Since the human body is mostly water, the pad acts as a fluid extension of the body to form an acoustical conduit to a sensitive hydrophone within the pad that detects body sounds. The sensing pad can be a hand-held version for the field medic or doctor, or a torso-sized pad incorporated into casualty transport hardware such as litters or gurneys. Acoustic analysis of the sensor-pad output can provide amplitude, phase, frequency, duration, rate, and correlative information that may be useful for medical diagnosis, patient care, and research. Data collected with prototype devices show excellent signal-to-noise ratios for heart and breath sounds; such devices could be used in the field to detect conditions such as irregular heartbeats, cardiac distress, obstructed airways, sucking chest wounds, fluid in the lungs, or other respiratory and circulatory emergencies. Joint time-frequency Fourier analysis of sensor output shows that human cardiopulmonary function contains infrasonic (sounds below 20 Hz) signals, which cannot be heard with human ears, but may be useful for medical diagnostics. If soldiers were equipped with small monitoring sensor pads with transmit capability to carry in contact with the torso, squad performance level could be assessed, or those missing in action could be medically interrogated from a remote location for heart and breathing sounds. The technology can also be used to monitor operators of vehicles or aircraft, and initiate appropriate safety actions in the event of sudden incapacitation resulting from weapons fire, heart attack, or blackout.

2.6.1-f AOTF Spectrometer for Water Pollutant Monitoring

N. Gupta, R. Dahmani - Army Research Laboratory, USA

The requirement for providing the soldier withclean drinking water is of utmost importance to the Department of Defense. A new joint services project has been initiated to carry out the research and development needed to find an experimental method suitable for this task. One of the techniques identified for this purpose is Raman spectroscopy, which provides highly reliable spectral signatures for chemicals and can be used as fingerprints for their identification. We at the Army Research Laboratory have been working on the development of a small, field-portable, rugged, high-resolution, high-sensitivity spectrometer that can be used in a very compact setup to carry out Raman spectral measurements for the detection of water pollutants. The spectrometer has been used to measure Raman spectra of nerve agent simulants.