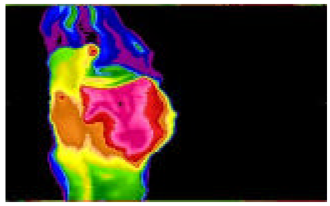
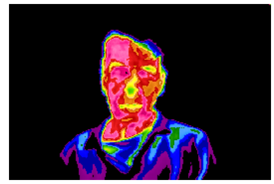
IR (Thermal) Imaging

Non-contact Monitoring Technology for Sleep Studies





Presentation Made to
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Thermal images from Teletherm Infrared (home1.gte.net/infrared)

NOTE: Slides have been re-ordered and additional information placed in a supplement

GAPS

Anyone who has ever experienced a sleep study knows how uncomfortable the wires and sensors used can be. The development of alternative non-contact technology to monitor relevant physiological processes would be of great help and importance. One promising technology is infrared [IR] (thermal) imaging. During the summer of 1998 after I received the July/August issue of **IEEE Engineering in Medicine and Biology** (devoted to IR imaging in medicine) and because of my background in physics and experience in aerospace & defense research, I began to seriously think about the application of IR imaging in sleep studies. This idea, which I felt would have been a unique opportunity to collaborate with my wife (Dr. Carol Rosen), was sadly interrupted by a family crisis that made that collaborative prospect impossible. I had been associated with the Yale Children's Sleep Center since its inception, having donated 100's of hours trouble shooting and significantly updating the data acquisition and analysis system as well as helping with many presentations and posters (Carol formed and was the first director of the lab until June 1999). I was finally able to make my pitch about this in September 1999 to the people who were presently in charge of the sleep lab (Drs. Gabriel Haddad and Lewis Kass). While Prof. Haddad expressed interest, nothing ever developed. Without initial data, this idea is not publishable. I have decided to take the unusual and unconventional route of a mass e-mailing and release it to the sleep research community in the hope that someone will recognize what a unique opportunity this presents. I no longer have the time or the luxury of being able to pursue this project.

What Does IR Imaging Measure?

IR imaging measures

the physiology of hemodynamics and the autonomic nervous system

by means of a precise spatial/temporal temperature measurement

This slide is pretty self-explanatory. We are observing the infrared radiation emitted by the skin, which behaves very close to that of a blackbody in the wavelength range 2-14 μm. While blood flow is the major factor influencing skin temperature, it is not quite that simple as shown in a later slide (Slide 5). Other factors such as the environmental temperature must be controlled so that the image mirrors only those physiological changes due, in our case, to the sleep state.

History of IR Imaging in Medicine

"Temperature is a long established indicator of health."

- **Premature use of IR imaging led to it being discredited by the majority of the medical community**
  - **The US pioneered the clinical use of IR imaging in the late 1960's in neurology, surgery, oncology, dentistry, and dermatology**
  - **Inadequate equipment**
  - **Little awareness of the scope and limitations of IR technology**
  - **Little understanding of the underlying physiological and pathophysiological manifestations it can measure**

The consequence of attempting to apply a technology before it has sufficiently matured can be disastrous. Such is the case with infrared (IR) imaging in medicine. Back in the 1960's, the technology was in its infancy. While people correctly recognized its promise, it was not ready to be put into practice. It would take decades of development to perfect focal plane arrays, uncooled detector technology, and have the computer capability as well as image processing algorithms and mass storage needed to handle digitized images, especially in real time. Unfortunately, the early failures have tainted IR imaging as almost a pseudo-science. In spite of the incredible advances made in this technology (mostly due to defense research), the medical community has been very slow to see the same promise that people had recognized so long ago

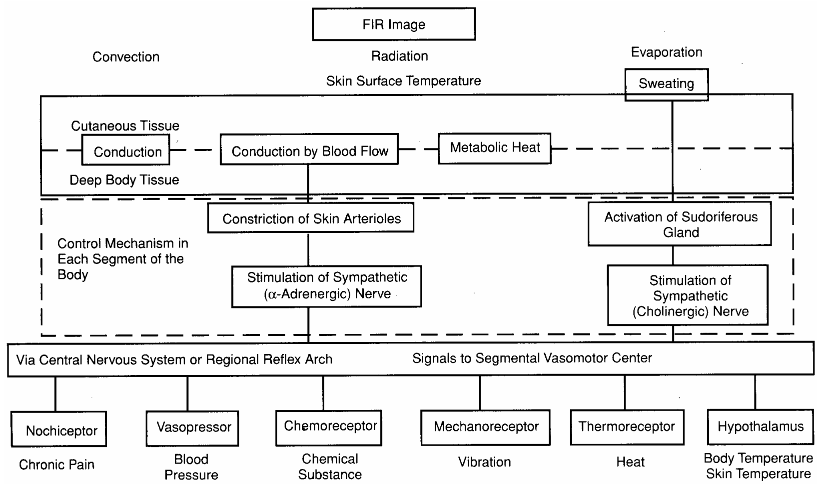
Areas of Potential Use

Neurology
Vascular Disorders
Arthritis & Rheumatism
Pain (management & control)
Surgery
Neonatology
Oncology
Tissue Viability
Emergency Medicine
Dermatology
Opthomology
Dentistry

SLEEP STUDIES

This slide lists the areas of potential use for IR imaging that have been discussed in the literature plus the one of interest I have added—SLEEP STUDIES. While we know that the core body temperature varies by about ±1 °C around 4 cycles/day with the lowest temperature occurring during sleep, no one has ever observed the spatial/temporal variations in skin temperature during sleep. Obviously, the head area is the easiest region of the body to observe. It is a region of rich contrasts that can be observed for correlation of temperature changes (i.e., blood flow) with phenomena like REM, apnea, etc. In fact the sensitivity and speed of the present state-of-the-art IR imaging system should be capable of detecting heart rate (possibly temple region or neck) and breathing (nose-mouth region) as well.

Factors Affecting Skin Temperature



I. Fujimasa , IEEE Eng. Med. and Biology, 17 (July/Aug 1998)

Do not be distracted by the seeming complexity of this chart. We are looking for consistent changes in the **thermal signature** (spatial/temporal patterns) of a patient with recorded physiological events (i.e., apnea, EEG, EKG, REM, CO_2/O_2, etc.). Once these corrrelations have been established, explanations of the underlying mechanisms, if needed, can be investigated – but it is not necessary in order to make use of the trends found.

Table 3. Main application areas of thermography and their diagnostic principles.

Main application area of thermographic examination	Diagnostic principles	Diagnosing techniques
Peripheral vascular diseases	To find abnormal angiologic thermatome	Sequential subtraction, thermal gradient and asymmetry detection
Local metabolic disorders	To find abnormal hot or cold areas and metabolic thermatome	Thermographic index
Chronic pain	To find abnormal dermatomal thermatome, myotomal thermatome, and angiologic thermatome	Asymmetry detection, and thermographic index
Autonomic nerve system disorders	To find abnormal dermatomal thermatome	Asymmetry detection, thermographic index and stress test
Inflammatory diseases	To find abnormal hot area and metabolic thermatome	Asymmetry detection, and thermographic index
Tumors	To find hot or cold areas, metabolic thermatome, and abnormal vascular pattern	Sequential subtraction, thermal gradient and asymmetry detection
Body temperature abnormalities	To analyze abnormal body temperature and discrepancy between skin and body temperature	Thermo-physiological test

I. Fujimasa , IEEE Eng. Med. and Biology, 17 (July/Aug 1998)

This slide and the next list medical uses of IR imaging that have been discussed in the literature. An application that has received a great deal of attention is detecting breast cancer. Even a recent issue of the **Ballistic Missile Defense Organization** [now known as the Missile Defense Agency] **Update** (issue 38, Summer 2001) has discussed this use [www.mdatechnology.net].

Pathophysiological Causes of Abnornmal Thermogram Patterns

Table 2. Abnormal thermogram patterns classified by the pathophysiological causes.

	Thermatomes	Definitions	References
1	Angiological thermatomes	Abnormal temperature regions caused by organic vascular abnormalities	[13]
2	Functional angiological thermatomes	Abnormal temperature regions caused by vascular disfunctions	[14]
3	Neuro-dermatomal thermatomes	Abnormal temperature bands caused by somatosensory neuronal disorders	[9]
4	Myotomal thermatomes	Abnormal temperature regions suspected by abnormal muscular blood flow rate	[15]
5	Metabolic thermatomes	Abnormal hot and/or cold spots caused by excessive and/or lower heat production and blood flow	[16]
6	Dynamic thermatomes at environmental temperature stress	Regions with abnormal reactions when a patient received an applied thermal load	[17]
7	Dynamic thermatomes at medication	Regions with abnormal reactions when a patient is given a medication	[18]
8	Dynamic thermatomes at various kinds of stress	Regions with abnormal reactions when a patient receives a load (various in type)	[19]

I. Fujimasa , IEEE Eng. Med. and Biology, 17 (July/Aug 1998)

IR Imaging & Sleep Studies

Potential correlation of spatial/temporal variations in temperature with

OSA

Sleep Stages

Heart and Breathing Rates

New Diagnostic Information

The initial study to demonstrate the feasibility of using IR imaging as a sleep study tool should be very easy. Digitally recording and storing image data as a function of time is all that would be required in the beginning. Correlations would have to be established with recorded physiological events in a large enough population of patients.

IR (Thermal) Imaging

Non-invasive

Non-contact

Completely harmless

Relatively inexpensive

Easy to Use

A PERFECT TECHNOLOGY FOR SLEEP STUDIES

This slide summarizes why IR imaging is a "perfect technology for sleep studies." **The thermal signature [spatial/temporal patterns] of a patient has the potential of becoming a powerful new diagnostic and monitoring tool**. It is an uncharted region that should yield new insights as well as correlations with physiological changes that occur during sleep.

Conclusion

Opportunity to pioneer the application of a new technology (IR [thermal] imaging) to sleep medicine

- **Easy (no equipment or software development needed initially)**
- **Low cost (equipment should be able to be borrowed for initial tests)**
- **Relatively small time commitment**

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Since I originally made this presentation, infrared imaging systems and computer capabilities have only gotten better. It is always much easier to be the first, to pioneer, the application of a new technology. If initial observations show promise, the more tedious and difficult task of engineering the findings into an easy to use automated sleep study system will be required. Obviously, patients move when they are sleeping. Some type of image tracking and registration will be necessary. Analyzing time variations in a single location is straightforward. Analyzing spatial variations with time is another matter (although there is a great deal of sophisticated image analysis software available -- however, it may be as simple as monitoring the temperature in certain key regions and noting how they change relative to each other). I hope that enough information has been presented to convince someone to pursue this exciting new application for IR imaging. If anyone does, please keep me informed and let me know what you discover (mdarosen@post.harvard.edu).

Supplementary Material

IR Imaging System Specifications

Table 1. The minimum requirements and recent features of a clinical FIR system.		
Specifications	**Japanese Industrial Standard of clinical FIR imaging system [9]**	**Up-to-date clinical FIR system**
Detectable temperature difference	0.1°C	0.05°C
Measurable temperature level	0°C-50°C	-20°C-300°C
Minimum number of pixels	10000 (100 x 100)	65536 (256 x 256) - 262144 (512 x 512)
Minimum frame rate	1 frame/sec.	7.5 frame/sec. -60 frame/sec.
Absolute temperature value	possible to read out directly from each pixel	

I. Fujimasa , IEEE Eng. Med. and Biology, 17 (July/Aug 1998)

This slide should be used as a guide for choosing a suitable camera. An uncooled or thermoelectrically cooled camera would be preferable (although for this initial study, a liquid nitrogen (LN_2) cooled camera would be acceptable [it may need to be refilled more than once during a given study]).

Types of Uncooled Focal Plane Arrays

- **Microbolometer [FIR]**
  - resistance varies with temperature
- **Ferroelectrics [FIR]**
  - dielectric constant varies with temperature
- **Quantum Well IR Photodetectors (QUIP) [NIR}**
  - current varies with radiation level
- **Photovoltaics (HgCdTe, InSb, Schottky barrier PtSi) [NIR-FIR]**
  - voltage varies with radiation level

Bibliography

"From Outer Space to Medical Imaging," **IEEE Engineering in Medicine and Biology Magazine**, vol. 17, no. 4 (July/August 1998). It was this issue and my background in physics and the aerospace industry that prompted me to think about the potential application of IR imaging to sleep studies.

Infrared Imaging: An Emerging Technology in Medicine, N. A. Diakides, p. 17.

Progress in the Measurement of Human Body Temperature, E. F. J. Ring, p.19.

Clinical Thermal Imaging Today, M. Anbar, p. 25.

Pathophysiological Expression and Analysis of Far Infrared Thermal Images, I. Fujimasa, p. 34

Investigating Deep Venous Thrombosis with Infrared Imaging, J. R. Harding, p. 43

Evaluating Asymmetrical Distributions through Image Processing, K. Mabuchi et al., p. 47

High-Resolution Infrared Technology for Soft-Tissue Injury Detection, M. Bales, p. 56.

An Uncooled IR Sensor with Digital Focal Plane Array, T. White et al., p. 60.

Biomedical Infrared Imaging in Japan, B. Harrison et al., p. 66.

Bibliography (cont.)

"Reaching for New Levels: The Growing Applications of Medical Infrared Imaging," **IEEE Engineering in Medicine and Biology Magazine,** vol. 19, no. 3 (May/June 2000). This was a follow-up to the 1998 issue.

Functional Infrared Imaging of the Breast, J. R. Keyserlingk et al., p. 30.

Applying Dynamic Thermography in the Diagnosis of Breast Cancer, Y. Ohashi et al., p. 42.

The Important Role of Infrared Imaging in Breast Cancer, J. F. Head et al., p. 52.

The Potential of Dynamic Area Telethermometry in Assessing Breast Cancer, M. Anbar et al., p. 58.

Increasing the Effective Resolution of Thermal Infrared Images, W. E. Snyder et al., p. 63.

Converting Far Infrared Image Information to Other Physiological Data, I. Fujimasa et al., p. 77.

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Other Selected Papers:

Finney, P., "IR Imaging with Uncooled Focal Plane Arrays," Sensors Magazine (October 1996), 36-44.

Giakos, G. C., "Emerging Imaging Sensor Technologies from Aerospace to Healthcare," IEEE Instrumentation & Measurement Magazine, vol. 1, no. 4 (December 1998), 16-19.

Jones, B. F., "A Reappraisal of the Use of Infrared Thermal Image Analysis in Medicine," IEEE Transactions on Medical Imaging, vol. 17, no. 6 (December 1998), 1019-1027.

Tosteson, T. D., Poque, B. W., Demidenko, E., McBride, T. O., and Paulsen, K. D., "Confidence Maps and Confidence Intervals for Near Infrared Images in Breast Cancer," IEEE Transactions on Medical Imaging, vol. 18, no. 12 (December 1999), 1188-1193.

Thornton, S. B.and Nair, S. S., "Parametric Studies of Human Thermal Mechanisms and Measurements," IEEE Transactions on Biomedical Engineering, vol. 47, no. 4 (April 2000), 444-451.

Anbar, M., Milescu, L., Naumov, A., Brown, C., Button, T., Carty, C. and AlDulaimi, K., "Detection of Cancerous Breasts by Dynamic Area Telethermometry," IEEE Engineering in Medicine and Biology Magazine, vol. 20, no. 5 (September/October 2001), 80-91.

A list of other references can be found at: **www.meditherm.com/therm_page5.htm**

Internet Resources

The internet is a wonderful source of both information about infrared technology and companies that could be potential partners in a preliminary investigation of the application of IR imaging in sleep studies. Because of the dynamics of high tech companies (including reorganizations and mergers), web sites can either disappear or change. It is bestto do a current search using one of the many search engines on the web. I only include a few sites below:

BAE Systems: Infrared Imaging Systems	www.iews.na.baesystems.com/iris/uncooled.htm
Teletherm Infrared	www.thermology.com
Inframetrics	www.inframetrics.com
SE-IR Corporation	www.seir.com
Compix	www.teleport.com/~compix/
Sierra Pacific Infrared	www.x26.com/medical.htm
Micro Health Systems, Inc.	www.mhs5000.com

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IR Imaging and Lying

An interesting potential application for IR imaging that recently made the news is its use to determine deceit by looking at the blood flow (temperature) around the eyes. While this has by no means been positively established, it is just another example of the versatility of IR imaging.

Ioannis Pavlidis, Norman L. Eberhardt, James A. Levine, "Seeing through the face of deception: Thermal imaging offers a promising hands-off approach to mass security screening," **Nature** (Brief Communications), vol. 45 (3 Jan 2002), p. 35