Final Progress Report for Research Projects Funded by Health Research Grants

Instructions: Please complete all of the items as instructed. Do not delete instructions. Do not leave any items blank; responses must be provided for all items. If your response to an item is "None", please specify "None" as your response. "Not applicable" is not an acceptable response for any of the items. There is no limit to the length of your response to any question. Responses should be single-spaced, no smaller than 12-point type. The report **must be completed using MS Word**. Submitted reports must be Word documents; they should not be converted to pdf format. Questions? Contact Health Research Program staff at 717-783-2548.

1. **Grantee Institution:** Temple University – of the Commonwealth System of Higher Education

2. **Reporting Period (start and end date of grant award period):** 01/1/2009 -12/31/2012

3. **Grant Contact Person (First Name, M.I., Last Name, Degrees):** Germaine Calicat, MLA

4. **Grant Contact Person's Telephone Number:** 215.204.7655

5. **Grant SAP Number:** 4100047651

6. **Project Number and Title of Research Project:** 13 - T*actile Imaging Sensor and Hyperspectral Data for Early Breast Cancer Detection*

7. **Start and End Date of Research Project:** 7/1/2009 – 5/31/2011

8. **Name of Principal Investigator for the Research Project:** Chang-Hee Won, Ph.D.

9. **Research Project Expenses**.

   9(A) Please provide the total amount of health research grant funds spent on this project for the entire duration of the grant, including indirect costs and any interest earned that was spent:

   $50,000

   9(B) Provide the last names (include first initial if multiple individuals with the same last name are listed) of **all** persons who worked on this research project and were supported with health research funds. Include position titles (Principal Investigator, Graduate Assistant, Post-doctoral Fellow, etc.), percent of effort on project and total health research funds expended for the position. For multiple year projects, if percent of effort varied from year to year, report in the % of Effort column the effort by year 1, 2, 3, etc. of the project (x% Yr 1; z% Yr 2-3).

Last Name	Position Title	% of Effort on Project	Cost
Won	Associate Professor, PI	5%	$ 4,500
Lee	Graduate Assistant	100%	$22,000

9(C) Provide the names of **all** persons who worked on this research project, but who *were not* supported with health research funds. Include position titles (Research Assistant, Administrative Assistant, etc.) and percent of effort on project. For multiple year projects, if percent of effort varied from year to year, report in the % of Effort column the effort by year 1, 2, 3, etc. of the project (x% Yr 1; z% Yr 2-3).

Last Name	Position Title	% of Effort on Project
Caroline	Professor	1%

9(D) Provide a list of **all** scientific equipment purchased as part of this research grant, a short description of the value (benefit) derived by the institution from this equipment, and the cost of the equipment.

Type of Scientific Equipment	Value Derived	Cost
None		

10. Co-funding of Research Project during Health Research Grant Award Period. Did this research project receive funding from any other source during the project period when it was supported by the health research grant?

Yes_____ No___X_____

If yes, please indicate the source and amount of other funds:

11. Leveraging of Additional Funds

11(A) As a result of the health research funds provided for this research project, were you able to apply for and/or obtain funding from other sources to continue or expand the research?

Yes_____ No_____X____

If yes, please list the applications submitted (column A), the funding agency (National Institutes of Health—NIH, or other source in column B), the month and year when the application was submitted (column C), and the amount of funds requested (column D). If you have received a notice that the grant will be funded, please indicate the amount of funds to be awarded (column E). If the grant was not funded, insert “not funded” in column E.

Do not include funding from your own institution or from CURE (tobacco settlement funds). Do not include grants submitted prior to the start date of the grant as shown in Question 2. If

you list grants submitted within 1-6 months of the start date of this grant, add a statement below the table indicating how the data/results from this project were used to secure that grant.

A. Title of research project on grant application	B. Funding agency (check those that apply)	C. Month and Year Submitted	D. Amount of funds requested:	E. Amount of funds to be awarded:
None	☐NIH ☐ Other federal (specify:_____) ☐ Nonfederal source (specify:_)			

11(B) Are you planning to apply for additional funding in the future to continue or expand the research?

Yes___X_____ No_____

If yes, please describe your plans:

NSF, NIH R01

12. Future of Research Project. What are the future plans for this research project?

I will continue to develop the tactile imaging system and submit proposals to NSF and NIH.

13. New Investigator Training and Development. Did students participate in project supported internships or graduate or post-graduate training for at least one semester or one summer?

Yes___X_____ No_____

If yes, how many students? Please specify in the tables below:

	Undergraduate	Masters	Pre-doc	Post-doc
Male			1	
Female				
Unknown				
Total			**1**	

	Undergraduate	Masters	Pre-doc	Post-doc
Hispanic				
Non-Hispanic			1	
Unknown				
Total			**1**	

	Undergraduate	Masters	Pre-doc	Post-doc
White				
Black				
Asian			1	
Other				
Unknown				
Total			**1**	

14. Recruitment of Out-of–State Researchers. Did you bring researchers into Pennsylvania to carry out this research project?

Yes_____ No____X_____

If yes, please list the name and degree of each researcher and his/her previous affiliation:

15. Impact on Research Capacity and Quality. Did the health research project enhance the quality and/or capacity of research at your institution?

Yes____X_____ No_____

If yes, describe how improvements in infrastructure, the addition of new investigators, and other resources have led to more and better research.

We established a research laboratory that performs tactile sensor research. Currently, I have two undergraduate and three graduate students working on tactile sensors research.

16. Collaboration, business and community involvement.

16(A) Did the health research funds lead to collaboration with research partners outside of your institution (e.g., entire university, entire hospital system)?

Yes_____ No____X_____

If yes, please describe the collaborations:

16(B) Did the research project result in commercial development of any research products?

Yes___X_____ No_____

If yes, please describe commercial development activities that resulted from the research project:

Applied for a patent titled, "Method and Apparatus for Surface and Subsurface Tactile Sensation Imaging" Temple Reference No.: 669CW, Provisional Patent Filed: July 9, 2010, Application No. 61/363,062, Patent Application with PCT Filed: 7 July 2011, International Application No. PCT/US2011/043203.

16(C) Did the research lead to new involvement with the community?

Yes_____ No_____X _____

If yes, please describe involvement with community groups that resulted from the research project:

17. Progress in Achieving Research Goals, Objectives and Aims.

List the project goals, objectives and specific aims (as contained in the grant agreement). Summarize the progress made in achieving these goals, objectives and aims for the period that the project was funded (i.e., from project start date through end date). Indicate whether or not each goal/objective/aim was achieved; if something was not achieved, note the reasons why. Describe the methods used. If changes were made to the research goals/objectives/aims, methods, design or timeline since the original grant application was submitted, please describe the changes. Provide detailed results of the project. Include evidence of the data that was generated and analyzed, and provide tables, graphs, and figures of the data. List published abstracts, poster presentations and scientific meeting presentations at the end of the summary of progress; peer-reviewed publications should be listed under item 20.

This response should be a DETAILED report of the methods and findings. It is not sufficient to state that the work was completed. Insufficient information may result in an unfavorable performance review, which may jeopardize future funding. If research findings are pending publication you must still include enough detail for the expert peer reviewers to evaluate the progress during the course of the project.

Health research grants funded under the Tobacco Settlement Act will be evaluated via a performance review by an expert panel of researchers and clinicians who will assess project work using this Final Progress Report, all project Annual Reports and the project's strategic plan. After the final performance review of each project is complete, approximately 12-16 months after the end of the grant, this Final Progress Report, as well as the Final Performance Review Report containing the comments of the expert review panel, and the grantee's written response to the Final Performance Review Report, will be posted on the CURE Web site.

There is no limit to the length of your response. Responses must be single-spaced below, no smaller than 12-point type. If you cut and paste text from a publication, be sure symbols print properly, e.g., the Greek symbol for alpha (α) and beta (ß) should not print as boxes (□) and include the appropriate citation(s). DO NOT DELETE THESE INSTRUCTIONS.

Objectives. The broad objective of this research is to investigate the use of a tactile image sensor and hyperspectral images to detect breast cancer. Specific aim one is to develop a tactile imaging sensor that will image the touch sensation of the breast. This will enable the system to detect the palpable breast cancer tumors. The second specific aim is to develop a hyperspectral imaging subsystem with a light source to detect the calcification of the breast tissues. This will enable the detection of non-palpable breast cancer detection.

Research Design and Methods. We developed a tactile imaging sensor that will quantify the touch sensation. Tactile sensation (palpation) is one of the most reliable methods of detecting breast tumors. We hypothesized that the healthy tissues will have similar elasticity throughout, and unhealthy tissues will have different elasticity. Thus, we will measure the softness/hardness of the tissues. Utilizing total internal reflection principle, the tactile imaging subsystem quantified the breast tissue elasticity, which in turn is used to determine malignant tumors.

Another subsystem consists of the hyperspectral camera subsystem, lighting subsystem, and processing subsystem. Hyperspectral camera is a combination of charge-coupled-device (CCD) camera with spectral information in each pixel. We used high intensity light emitting diodes and a liquid crystal tunable filter. We identified which band will be most effective in detecting calcification.

Research Outcomes and Benefits. Early and reliable detection of breast cancer is an important issue. Utilizing multiple modalities will improve the reliability of breast cancer detection and decrease false alarms. A novel tactile sensor subsystem will detect tumors by palpation, and a novel hyperspectral subsystem will detect calcification of the breast tissues. We propose to investigate the feasibility of such a system. If successful, a portable system will detect cancer cells with high accuracy in almost real-time. This will allow breast cancer screening to be performed in non-hospital settings. If this preliminary project is successful and a system is developed, then the impact will be in three areas: breast cancer early detection, detection from a remote location, and intraoperative tool.

One of the most common reasons for irregular breast cancer physical examination is procrastination. People are simply too busy to make an appointment to see a doctor for a potential problem that may or may not be there. One of the impacts of this project is to solve this problem by providing a Tactile and Hyperspectral System near the patients. For example, this system could be used in primary care physician's office.

Tactile and Hyperspectral System can be used in remote locations, where breast cancer specialists are not available. For example, in a rural area where there are no major hospitals nearby, a general practioner may have a Tactile and Hyperspectral System to detect malignant tumor.

Summary of Research Completed, We developed an optical tactile sensor based on the single layer silicone elastomer and the total internal reflection principle. We have built a sensor and performed the normal force computation from the tactile images. Then we determined the calcification using a hyperspectral camera.

Tactile Sensor Design. We have developed a simple prototype tactile sensor using a single layer silicone, a light emitting diode (LED), a camera, and a computer. The waveguide was made of transparent Polydimethylsiloxane silicone gel. The refractive index of the silicone is 1.43. The light source is a cool white micro LED with a diameter of 1.8 mm. We used a complementary metal-oxide-semiconductor (CMOS) camera with 768 x 492 pixels with 8.4 μm x 8.4 μm pixel size. This system was developed to test the feasibility of imaging the tactile sensation. The resolution, sensitivity, and specificity were not optimized.

We pressed the sensor with varying force and as the force was increased the brightness of the image also increased. The sensor was made from silicone powder, but due to the lack of the proper equipment and the unavailability of the necessary clean environment, silicone gel resulted with some impurities.

Tumor Characterization. Characterizing and locating embedded tumors will greatly enhance the detection and treatment of breast cancer. In this project, a novel tactile imaging sensor, that is capable of detecting and characterizing the sub-surface object, was designed, built, and tested. Using the salient features of the captured image, we estimated inclusion characteristics such as size, depth, and Young's modulus. To test the performance of the proposed system, we use a realistic tissue phantom with embedded stiff inclusions. The experimental results showed that the proposed system can detect inclusions and provide the relative values of inclusion's mechanical properties. Using these relative values, we can discern malignant and benign tumors.

We hypothesized that we can estimate the normal force from the gray scale values. In order to verify our hypothesis, we performed an experiment with many different normal forces and obtained the corresponding images. We used a stainless steel indenter with a spherical shaped tip with the diameter of 3mm. Then we integrated the gray scale values to obtain correlation between the integrated pixel values and the normal force. Even though more careful measurements and analysis must be performed, we showed that the gray scale values are linearly related to the normal force.

Hyperspectral Imaging System for Breast Calcification Characterization. Hyperspectral imaging system (HIS) is a novel method to generate a spectral characteristic map of region of interest based on the chemical composition. Previously, HIS has been used in non-medical applications including satellite investigation to find minerals on the ground or to access the condition of agriculture fields. Recently, HIS has been applied to the investigation of pathological changes in living tissue of animal and human. It has proven that HIS can provide valuable information as to the health or disease of tissue that sometimes other modalities are unavailable. HIS is a remote sensing technology to create 2-dimensional image having spectral information in each pixel. This information can be interpreted as the gradient map of species. It means HIS is a method of imaging spectroscopy combining the chemical specificity of spectroscopy with spatial information of imaging.

Biological tissues have optical signatures that reflect their chemical characteristics. The primary compositions in human tissue are oxyhemoglobin (HbO_2) and deoxyhemoglobin (Hb). The Hb further breaks down into melanin, lipids and water (oxygenation). Total hemoglobin (HbT) indicates the combined quantities of HbO_2 and Hb. In near infrared (NIR) region, HbO_2 and Hb

are major sensitive spectrum absorber. Since many diseases have specific effects on tissue oxygen and blood supply, tissue oxygenation and total hemoglobin concentration are major indicators of viability and tissue health. Here, we manly focus on the NIR region, particularly the short wavelength NIR of 650 to 1100 nm. NIR region has deeper tissue penetration than other regions. By comparing the acquired spectrum absorption measurement in NIR region, information about type, location and relatively concentration of chemical decomposition about the tissue can be quantified. As far as we know, non-invasive, real time, local measurement of tissue oxygenation and total hemoglobin is still not commercially available. We constructed and characterized HIS capable of detecting photons in the NIR wavelength region to characterize the tissue condition. HIS we proposed here has several advantages compared to other modalities such as CT and MRI. It penetrated into biological tissue deeply without radiation exposure such as CT, thus functional imaging with non-invasive and non-radioactive in real time is available. In addition it is portable and low cost compared to MRI or CT.

The object of this work is to design HIS and investigate the ability of detecting calcification (Hydroxyapatite) in the breast. HIS is integrated with charged coupled device (CCD) and liquid crystal tunable filter (LCTF) to automatically capturing the spectrum information of Hydroxyapatite. LCTF controller was tuned to scanning from 650 nm to 1100 nm bands with 5 nm steps.

For the breast calcification characteristic experiments, Microcrystalline Hydroxyapatite 1200 mg is prepared. Totally 91 spectral band images, each image of 1392 $\times$ 1040 pixels in size was obtained within 23 seconds. The 500W lighting source is used for illumination. We graphed the spectrum characteristic of Microcrystalline Hydroxyapatite. It revealed the peak of 760 nm, 805 nm, 855 nm, 905 nm, and 960 nm. Thus, we conclude that we can detect calcification (hydrosyapatite) using a hyperspectral camera.

<u>Conclusions.</u> A novel tactile imaging sensor capable of characterizing the inclusion in the tissue was designed and experimentally evaluated. To emulate the human finger layer, a multilayer optical waveguide was fabricated as the main sensing probe. The total internal reflection principle (TIR) was used to obtain the high resolution tactile image. We analyzed the feasibility of the TIR using wave optics, which clearly showed the tactile image when the sensing probe was compressed. Then we utilized geometric optics to analyze the light illumination angles. The performance of the tactile imaging sensor was experimentally verified using tissue phantoms with embedded hard inclusions. The experimental results showed that the relative size and hardness estimation errors were smaller than the relative depth estimation errors. If the inclusion's size was smaller, the estimation error was also smaller. Also the shallower depth inclusion case has smaller depth estimation error than the inclusions embedded deeper. Furthermore, if the Young's modulus of an inclusion was smaller, the estimation error was smaller than the higher Young's modulus case. We conclude, however, that we could distinguish between soft, medium, and hard inclusions, which will allow us to distinguish malignant and benign tumors. This work is the initial step towards achieving a tactile imaging sensor for embedded breast tumor detection and characterization.

The results were presented in the following conferences.

[1] Jong-Ha Lee, Chang-Hee Won, “High Resolution Tactile Imaging Sensor for Inclusion

Detection and Identification," *The First AMA-IEEE Medical Technology Conference on Individualized Healthcare*, Washington DC, March 21-23, 2010.

[2] Jong-Ha Lee, Chang-Hee Won, "Inclusion Mechanical Property Estimation using Tactile Images, Finite Element Method, and Artificial Neural Network," *Proceedings of IEEE EMBC 11*, 33th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Boston MA.

[3] Lee J.H., Nathalia Garcia-Acosta, Kenny Te, and Won C.H., (2011)"Tactile Sensation Imaging System for Inclusion Mechanical Property Characterization," *Proceeding of SPIE*, BiOS, SPIE Photonics West, 22-27 January, San Francisco, California, USA, Volume 7890, pp. 78901D-1 to 78901D-15.

18. Extent of Clinical Activities Initiated and Completed. Items 18(A) and 18(B) should be completed for all research projects. If the project was restricted to secondary analysis of clinical data or data analysis of clinical research, then responses to 18(A) and 18(B) should be "No."

18(A) Did you initiate a study that involved the testing of treatment, prevention or diagnostic procedures on human subjects?

_____Yes
___X__No

18(B) Did you complete a study that involved the testing of treatment, prevention or diagnostic procedures on human subjects?

_____Yes
__X___No

If "Yes" to either 18(A) or 18(B), items 18(C) – (F) must also be completed. (Do NOT complete 18(C-F) if 18(A) and 18(B) are both "No.")

18(C) How many hospital and health care professionals were involved in the research project?

_____Number of hospital and health care professionals involved in the research project

18(D) How many subjects were included in the study compared to targeted goals?

_____Number of subjects originally targeted to be included in the study
_____Number of subjects enrolled in the study

Note: Studies that fall dramatically short on recruitment are encouraged to provide the details of their recruitment efforts in Item 17, Progress in Achieving Research Goals, Objectives and Aims. For example, the number of eligible subjects approached, the number that refused to participate and the reasons for refusal. Without this information it is difficult to discern whether eligibility criteria were too restrictive or the study simply did not appeal to subjects.

18(E) How many subjects were enrolled in the study by gender, ethnicity and race?

Gender:
_____Males
_____Females
_____Unknown

Ethnicity:
_____Latinos or Hispanics
_____Not Latinos or Hispanics
_____Unknown

Race:
_____American Indian or Alaska Native
_____Asian
_____Blacks or African American
_____Native Hawaiian or Other Pacific Islander
_____White
_____Other, specify:_____
_____Unknown

18(F) Where was the research study conducted? (List the county where the research study was conducted. If the treatment, prevention and diagnostic tests were offered in more than one county, list all of the counties where the research study was conducted.)

19. Human Embryonic Stem Cell Research. Item 19(A) should be completed for all research projects. If the research project involved human embryonic stem cells, items 19(B) and 19(C) must also be completed.

19(A) Did this project involve, in any capacity, human embryonic stem cells?
_____Yes
___X___ No

19(B) Were these stem cell lines NIH-approved lines that were derived outside of Pennsylvania?
_____Yes
_____ No

19(C) Please describe how this project involved human embryonic stem cells:

20. Articles Submitted to Peer-Reviewed Publications.

20(A) Identify all publications that resulted from the research performed during the funding period and that have been submitted to peer-reviewed publications. Do not list journal

abstracts or presentations at professional meetings; abstract and meeting presentations should be listed at the end of item 17. **Include only those publications that acknowledge the Pennsylvania Department of Health as a funding source** (as required in the grant agreement). List the title of the journal article, the authors, the name of the peer-reviewed publication, the month and year when it was submitted, and the status of publication (submitted for publication, accepted for publication or published.). Submit an electronic copy of each publication or paper submitted for publication, listed in the table, in a PDF version 5.0.5 (or greater) format, 1,200 dpi. Filenames for each publication should include the number of the research project, the last name of the PI, the number of the publication and an abbreviated research project title. For example, if you submit two publications for PI Smith for the "Cognition and MRI in Older Adults" research project (Project 1), and two publications for PI Zhang for the "Lung Cancer" research project (Project 3), the filenames should be:

Project 1 – Smith – Publication 1 – Cognition and MRI
Project 1 – Smith – Publication 2 – Cognition and MRI
Project 3 – Zhang – Publication 1 – Lung Cancer
Project 3 – Zhang – Publication 2 – Lung Cancer

If the publication is not available electronically, provide 5 paper copies of the publication.

Note: The grant agreement requires that recipients acknowledge the Pennsylvania Department of Health funding in all publications. Please ensure that all publications listed acknowledge the Department of Health funding. If a publication does not acknowledge the funding from the Commonwealth, do not list the publication.

Title of Journal Article:	Authors:	Name of Peer-reviewed Publication:	Month and Year Submitted:	Publication Status (check appropriate box below):
1. Tactile Elasticity Imaging Sensor and Non-rigid Pattern Matching Algorithm	Jong-Ha Lee, Chang-Hee Won	*IEEE Sensors Journal*	Sept 2010	☐Submitted ☐Accepted ■Published

20(B) Based on this project, are you planning to submit articles to peer-reviewed publications in the future?

Yes_____ No___X_____

If yes, please describe your plans:

21. Changes in Outcome, Impact and Effectiveness Attributable to the Research Project. Describe the outcome, impact, and effectiveness of the research project by summarizing its impact on the incidence of disease, death from disease, stage of disease at time of diagnosis, or other relevant measures of outcome, impact or effectiveness of the research project. If there were no changes, insert "None"; do not use "Not applicable." Responses must be

single-spaced below, and no smaller than 12-point type. DO NOT DELETE THESE INSTRUCTIONS. There is no limit to the length of your response.

None.

22. Major Discoveries, New Drugs, and New Approaches for Prevention Diagnosis and Treatment. Describe major discoveries, new drugs, and new approaches for prevention, diagnosis and treatment that are attributable to the completed research project. If there were no major discoveries, drugs or approaches, insert "None"; do not use "Not applicable." Responses must be single-spaced below, and no smaller than 12-point type. DO NOT DELETE THESE INSTRUCTIONS. There is no limit to the length of your response.

None.

23. Inventions, Patents and Commercial Development Opportunities.

23(A) Were any inventions, which may be patentable or otherwise protectable under Title 35 of the United States Code, conceived or first actually reduced to practice in the performance of work under this health research grant? Yes__X_____ No_____

If "Yes" to 23(A), complete items a – g below for each invention. (Do NOT complete items a - g if 23(A) is "No.")

a. Title of Invention: Apparatus and Method for Surface and Subsurface Tactile Sensation Imaging

b. Name of Inventor(s): Chang-Hee Won

c. Technical Description of Invention (describe nature, purpose, operation and physical, chemical, biological or electrical characteristics of the invention):

   The invention relates to a tactile sensor, methods of using and manufacturing the tactile sensor, and methods and apparatuses for processing the information generated by the tactile sensor, and more specifically to tactile sensors that utilize a flexible transparent optical waveguide that uses scattered light for determining properties of surface materials and subsurface inclusions.

d. Was a patent filed for the invention conceived or first actually reduced to practice in the performance of work under this health research grant?
   Yes_____X_____ No____

   If yes, indicate date patent was filed:

e. Was a patent issued for the invention conceived or first actually reduced to practice in the performance of work under this health research grant?
Yes_____ No___X (pending)

If yes, indicate number of patent, title and date issued:

Patent number: PCT/US2011/043203
Title of patent: Apparatus and Method for Surface and Subsurface Tactile Sensation Imaging
Date issued: Patent Application with PCT Filed: 7 July 2011

f. Were any licenses granted for the patent obtained as a result of work performed under this health research grant? Yes_____ No___X

If yes, how many licenses were granted?_____

g. Were any commercial development activities taken to develop the invention into a commercial product or service for manufacture or sale? Yes__ No___X

If yes, describe the commercial development activities:

23(B) Based on the results of this project, are you planning to file for any licenses or patents, or undertake any commercial development opportunities in the future?

Yes__X_____ No_____

If yes, please describe your plans:

Temple University of Technology Transfer is looking for companies to license this technology.

24. Key Investigator Qualifications. Briefly describe the education, research interests and experience and professional commitments of the Principal Investigator and all other key investigators. In place of narrative you may insert the NIH biosketch form here; however, please limit each biosketch to 1-2 pages.

Chang-Hee Won

NAME Chang-Hee Won	POSITION TITLE Associate Professor
eRA COMMONS USER NAME wonc2006	

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	YEAR(s)	FIELD OF STUDY
University of Notre Dame, Indiana, USA	B.S.	1985-1989	Electrical Engineering
University of Notre Dame, Indiana, USA	M.S.	1989-1992	Electrical Engineering
University of Notre Dame, Indiana, USA	Ph.D.	1992-1995	Electrical Engineering

A. Positions and Honors

Positions and Employment

2005-2009 Assistant Professor, Department of Electrical and Computer Engineering, Temple University, Philadelphia, PA

2009-present Associate Professor, Department of Electrical and Computer Engineering, Temple University, Philadelphia, PA

Professional Activities and Honors

Institute of Electrical and Electronics Engineers (IEEE) Engineering in Medicine and Biology Society
Institute of Electrical and Electronics Engineers (IEEE) Control Society
The Institute of Navigation (ION)

B. Selected Peer-Reviewed Publications (in chronological order)

1. Chang-Hee Won, Jong-Ha Lee, and Nathaniel Marchetti**,** (2007) **"**Image Overlay Method for Lung Volume Reduction Surgery Using Nonrigid Image Registration," *Proceedings of BMES 2007 Annual Fall Meeting*, Los Angeles, CA, Sept. 26-29, 2007.
2. Jong-Ha Lee, Chang-Hee Won, Seong G. Kong, (2008) "Estimation of Operative Line of Resection Using Preoperative Image and Nonrigid Registration," *Proceedings of IEEE EMBC 08*, 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, August 20-24.
3. Jong-Ha Lee, Chang-Hee Won, (2008) "Estimation of Preopertive Region of Interest without Corresponding Points using Robust Point Matching," Proceedings of *IEEE EMBC '08*, Vancouver, Canada.
4. Jong-Ha Lee, Chang-Hee Won,(2009) "Characterization of Lung Tissues using Liquid-Crystal Tunable Filter an Hyperspectral Imaging System," *Proceedings of IEEE EMBC 09*, 31th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Minneapolis, MN.

5. Jong-Ha Lee, Chang-Hee Won, (2010) "High Resolution Tactile Imaging Sensor for Inclusion Detection and Identification," *The First AMA-IEEE Medical Technology Conference on Individualized Healthcare*, Washington DC, March 21-23.
6. Lee J. H., Won C.H., Yan K., Yu Y., and Liao L. (2010) "Tactile sensation imaging for artificial palpation," *Haptics: Generating and Perceiving Tangible Sensations*, A.M.L. Kappers et al. (Eds.): Eurohaptics 2010, Part I, Lecture Notes in Computer Science, Springer-Verlag Berlin Heidelberg, Vol. 6191, pp. 373-378.
7. Jong-Ha Lee, Chang-Hee Won, Nathaniel Marchetti, (April 2010) "Determining the operative line of resection for image-guided emphysema surgery using a laser scanner and non-rigid registration," *The International Journal of Medical Robotics and Computer Assisted Surgery*, Vol. 6, pp.239-249.
8. Lee J.H., Won C.H., Yan K., and Yu Y. (2010) "Design and Evaluation of an Optical Tactile Imaging Device for Tumor Detection," 52nd Annual Meeting of American Association of Physicists and Medicine (AAPM), Philadelphia, PA, July 18-22.
9. Lee J.H., Nathalia Garcia-Acosta, Kenny Te, and Won C.H., (2011) Tactile Sensation Imaging System for Inclusion Mechanical Property Characterization," *Proceeding of SPIE*, BiOS, SPIE Photonics West, 22-27 January, San Francisco, California, USA, Volume 7890, pp. 78901D-1 to 78901D-15.
10. Chang-Hee Won, Jong-Ha Lee, Kathleen Reilly and Dina Caroline , (2011) "Optical Tactile Imaging System for Quantification and Display of Breast Tumors," *Proceedings of BMES 2011 Annual Fall Meeting*, Hartford, Connecticut, accepted for publication.
11. Jong-Ha Lee, Chang-Hee Won. (2011). "Tactile Elasticity Imaging Sensor and Non-rigid Pattern Matching Algorithm," *IEEE Sensors Journal*, published on the web, 28 January 2011.
12. Jong-Ha Lee and Chang-Hee Won. (2011) "Topology Preserving Relaxation Labeling for Non-rigid Point Matching," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 33, No. 2, pp.427-432.

Patents

Chang-Hee Won, "Modular Navigation System and Method," U.S. Patent, filed, December 2008.

Chang-Hee Won, "Apparatus and Method for Surface and Subsurface Tactile Sensation Imaging," Temple University, Provisional Patent Application Filed, July 9, 2010.

D. Research Support

Current Research Support

Principal Investigator, "AIS: Nonlinear Statistical Control Using Neural Networks," NSF, ECCS-Power, Controls, and Adaptive Networks, May 2010-April 2013.
We investigate using advanced control theory and neural networks for accurate targeting problem.