Quantifying Radiation Induced Skin Reaction using Skin Parameters Quantification Sensor Probe and 3-D Stereo Imaging Technique for Minimization of Position Uncertainty

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INTRODUCTION

During radiation therapy, the healthy tissue that surrounds the cancerous cells gets exposed to the radiation along with the unhealthy tissue. Though radiation plans are designed to avoid exposing the healthy tissue to radiation, adverse skin reactions are quite common. The skin that is exposed to the high intensity radiation responds by progressing from erythema to dry desquamation followed by moist desquamation [***1***]. Various qualitative methods to assess the amount of reaction include visual assessment tools like Radiation Therapy Oncology Group Scoring System (RTOG) and Radiation Induced Skin Reaction Assessment Scale (RISRAS) [***2***]. Skin viscoelasticity measurement tools and Reflectance Spectroscopy have been used as reaction quantifying devices [***3***] [***4***].Other methods include capturing digital images to study the damage. The quantification of the damage has been accomplished by measuring a dimensionless erythema and melanin index [***5***].The proposed method in this study deals with a probe design that can quantify the skin reaction using the integration of a set of sensors. The probe uses a combination of sensors to acquire data from the patient's skin. In particular, relative changes in temperature and skin resistance are known to be indications of damaged skin. To measure these quantities, the probe utilizes a precision infrared thermometer for temperature measurement, and a galvanic skin resistance measuring circuit, to quantify the amount of damage present in the irradiated skin.A 3-D stereo imaging technique is being used for position determination. The uncertainty is overcome by finding the position and orientation of body surface with respect to a reference. The method consists of using reference markers and tracking the position and orientation of reference markers present on the probe. The experiments have been conducted on a healthy human hand and the changes in skin conductance and temperature have been observed. The position determination has been as close as 2.5 mm.

PROBE DESIGN

In order to design the hand-held skin damage quantification clinical probe, the first step involved the identification of the sensors for the quantification. The sensors that were found feasible to be embedded into a single probe head were identified as non-contact infrared temperature sensor, the galvanic skin resistance sensor and the force sensor. Infra-red thermography is a phenomenon used to help detect cancer affected cells [***6***] [***7***]. The temperature in damaged cells is greater than the healthy cells due to the high volume of blood flow in damaged unhealthy cells, therefore it is deduced that infra-red temperature sensors help quantifying the damage. Changes in skin resistance may also be considered as a phenomenon that can help quantify the skin reaction [***8***].To study the change in skin resistance with the amount of applied force, a force sensor was also included in the design. Considering these sensing parameters, the device primarily consists of an infra-red sensor, galvanic skin resistance (GSR) sensor and a force sensor. The infrared sensor that was chosen for this application is the Melexis MLX90615[1] non-contact digital infrared thermometer. This sensor uses an IR sensitive thermopile detector integrated circuit (IC) and a signal conditioning application specific integrated circuit (ASIC) in a 4.7mm diameter package. This sensor was chosen because of its high accuracy, low noise capability, and small field-of-view lens aperture allowing for a temperature reading to be focused on a small area of the skin. The sensor is designed for medical applications and is pre-calibrated to the human skin temperature range providing an accuracy of +/- 0.1°Cand a measurement resolution of 0.02°C.A total of five Infra-red sensors were mounted in a single probe sensor head in order to obtain a differential comparison between adjoining tissues at a distance of 10mm. For experimental results, skin resistance may

[1]http://www.melexis.com/Assets/IR_sensor_thermometer_MLX90615_Datasheet_5477.aspx

also be considered as a phenomenon that can quantify the skin reaction; therefore a galvanic skin resistance sensor is also used. Here the potential difference between two electrodes placed on the skin gives the conductance of the skin between the points of contact. The GSR sensor is designed such that reliable information can be obtained when the GSR sensor sits on the skin tissue. Special attention was given for choosing the material of the GSR such that it is conductive but at the same time does not absorb too much heat from the body surface, therefore silver electrodes have been considered. The galvanic skin resistance sensor output changes with the amount of force being applied, therefore while taking a set of readings the amount of force applied should be kept constant. Hence a force sensor is used to take the readings at a constant application force. The force sensor used is a piezoresistive based force sensor, Honeywell FS03[2], it has a range up to 3 pounds and is temperature compensated over 5ºC to 50ºC temperature ranges. It is designed for medical applications and has linearity of +/- 1 % Full Scale Span.

After the sensors have been finalized, the electronic circuitry is developed to acquire useful data from the sensors. Advanced designing, filtering and platform techniques were used for the development of the electronic module. Circuit design involved designing and testing low power and single supply circuits (attenuators, integrators, amplifiers, etc.) and interfacing with a communication module. Sensor data acquisition and processing is done through the Texas Instruments controller MSP430F16. The MSP430 microcontroller was chosen because of its low cost and low power consumption features. IAR Embedded Workbench Integrated Development Environment (IDE) was used to program and debug the controller. All the digitized signals were tested using the Intronix 34 channel Logic Analyzer.

Once the circuitry has been finalized and tested, the printed circuit boards were designed using ORCAD/PROTEL software and given to an external fabricator for fabrication. A major challenge with the hardware circuit modules is to minimize battery power consumption in order to increase battery life. Furthermore, the size of the batteries would critically affect the size of the overall product. The solution to these issues is the optimization of the hardware and embedded software designs to accomplish the optimum tradeoff between battery size and battery life.

[2]http://sensing.honeywell.com/index.cfm?ci_id=140301&la_id=1&pr_id=144042

The following block diagram gives an overview of the system.

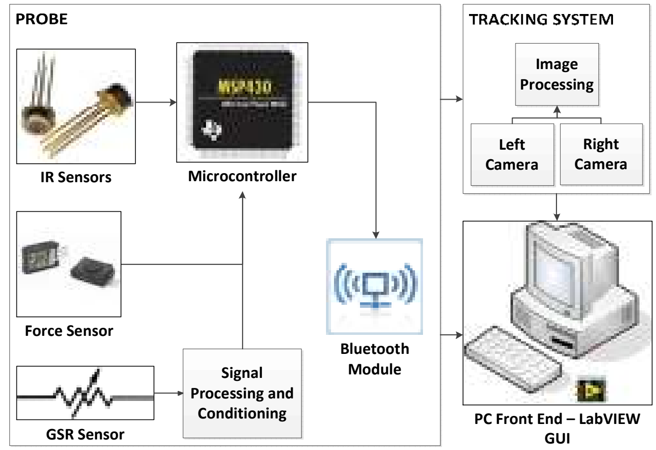


Figure 1: Skin Parameter Quantification System

The second phase of the probe development is the design of the sensor head. Once the sensors have been identified, they have to be embedded together in a single probe head. Designing of the probe sensor head is done such that all the stimuli initiated sensors simultaneously sit on the skin when the probe makes contact with the patient. The design aims to concentrate the measurements on a small area (12 mm radius) of the skin in order to obtain focused data that could be effectively correlated. The force sensor will be placed inside the body of the probe in order to detect the amount of force being applied by the physician through the GSR sensor. This is important as a comparative study between various readings of the GSR sensors is true only if the readings are taken at the same amount of applied pressure. The infrared sensors are placed such that they have a full field of view. The challenge in the design was to provide all the sensors with a necessary field of view in a 12 mm radius area. To accomplish this, the sensor head design was made through the assembly of three circular discs. The first disc carried the five infra-red sensors; the second disc carried the GSR sensor such that the GSR sensor could move freely through the infrared sensor disc. The GSR sensor disc is kept free inside the assembly so that it can convey the applied amount of pressure. The purpose of the third disc is to fix the force sensor. The probe sensor head is shown below along with an exploded view of the assembly.

Figure 2:Probe Sensor Head(CAD rendering, Prototype)

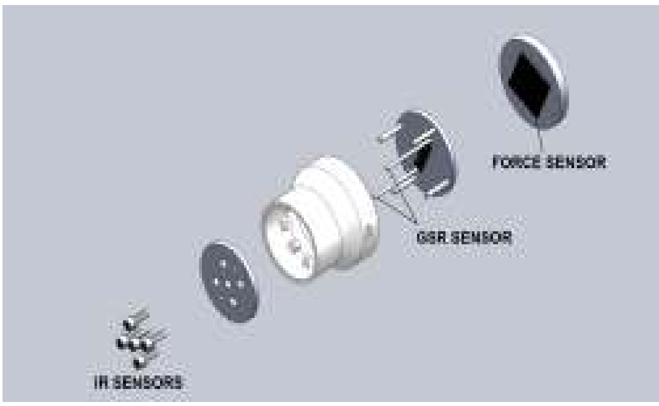


Figure 3: Probe Sensor Head Assembly

Another major component of the probe design was to come up with an ergonomically efficient enclosure. Using compact electronic module designing techniques and the computer-aided-design software SolidWorks, sensors along with electronic circuitry were architectured into the enclosure. The prototype was developed using rapid prototyping techniques and a 3-D printer. A CAD rendering along with the prototype of the assembled probe is shown.

Figure 4: Probe: (CAD rendering, Prototype)

COMMUNICATION PROTOCOLS

In the initial stage an RS-232 serial communication channel is used for transferring obtained signals to a computer.As wireless systems show great potential to significantly enhance the usability of medical devices; the functionality of the device is enhanced by using a Bluetooth wireless system for data communication between the sensor probe and the data logger. Through this the physician will have the freedom to move around and will eliminate the hassle of wires and cables. Bluetooth wireless technology was chosen for its ability to transmit data over a short range efficiently and reliably and also because it uses a fast acknowledgement and frequency-hopping scheme to make the link robust, even in noisy radio environments. Bluetooth also offers the advantage of being a relatively low power wireless communication protocol. The Bluetooth used is the LMX9838SB; the LM9838 dongle3.0 is to be used in the initial testing phase. The technical risk involved is that communication standards have to fulfill medical environment standards and FCC (Federal Communications Commission) standards compliance has to be met. Therefore provision has also been kept to use USB serial communication instead of the Bluetooth.

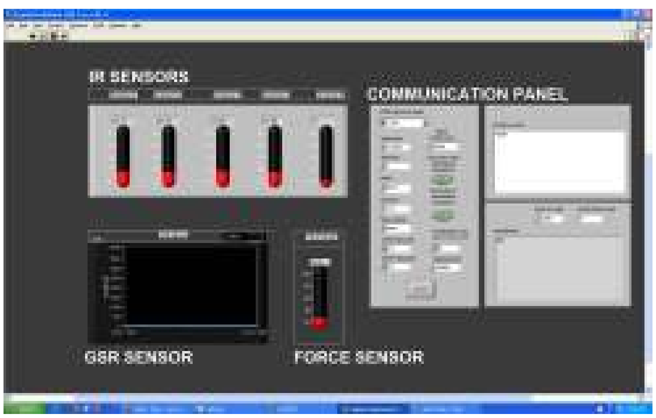
The captured data is presented using the LabVIEW graphical user interface (GUI). The software integrates the previously mentioned components and gives a graphical image of the obtained results. Furthermore, any post processing techniques could be toggled by the physician through this interface. This is a real-time application; the controller receives multiple inputs from various sensors, conditions it and communicates with the computer using the specified communication protocol. Lastly, the obtained data is displayed through National Instruments LabVIEW software. All the sensor outputs are displayed concurrently and in real-time via the GUI.

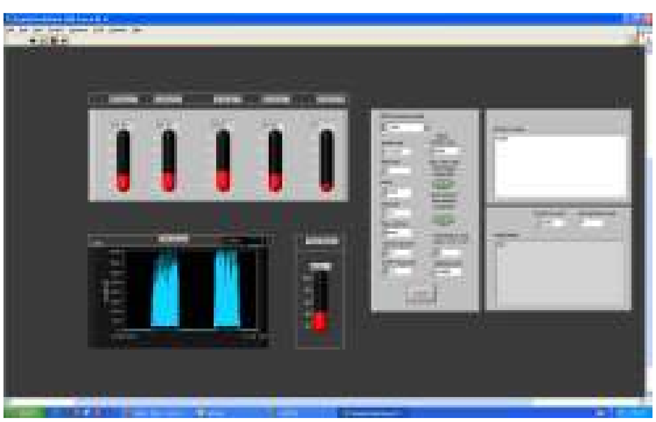
TRACKING SYSTEM

The vision system is used to track the position of the probe in real-time. The system consists of two binocular cameras (GIOTTOS MODEL No: AST-36CS) with a resolution of 756*480. Hence in real-time, an actual map of the sensor data with respect to the position is obtained. The position determination obtained is as close as 2.5 mm.

CONCLUSION

A sensor probe that can quantify the adverse skin reaction due to radiation exposure was developed. The probe has been tested on a healthy human hand. Images of the GUI are shown below. The red thermometers show the five IR sensor temperatures. It can be seen that one of the IR sensors is not showing any output, as during fabrication of sensor head, one of the IR sensors got damaged. This provides a good comparative index. The Blue waveform shows the GSR sensor reading and time history. To the right of the GSR waveform, the pressure sensor indicator is shown. The first image shows a screenshot of the GUI when the probe is idle. The second image shows the probes response to making contact with the skin.The GSR and the pressure sensors response is made clear by comparing these two images. Note that all sensors are being activated simultaneously when the probe contacts the patient’s skin.





This probe has the potential to be used for early detection of skin damage due to radiation exposure. The next step is to gather experimental data through clinical trials and test the results against different levels and severities of damaged skin.

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