Towards the Real-time Measurement of the Subsurface Temperatures of Pressure Sores

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***Abstract*—This report summarizes the main outcomes of the proposed work presented to the 2014 IEEE MTT-S Graduate Fellowship for Medical Applications. The research objective of this proposal is to perform the preliminary steps in engineering a diagnostic tool designed to monitor human health. The device will non-invasively, wirelessly, and accurately extract absolute subsurface temperature information from different depths within the human body. The approach taken will be to design and characterize a biomedical radiometer, and provide models to account for electromagnetic interactions between the human body and the monitoring device system. Ultimately, this work will benchmark the performance of a microwave radiometer system designed to measure the real-time absolute subsurface temperature of a human pressure ulcer phantom.**

***Index Terms*—Microwave radiometry, Subsurface sensing, Temperature, Pressure sores**

I. Introduction

In 2012, the US Department of Health & Human Services identified that 3 million adults suffer from pressure sores in the US, with prevalence rates in health care environments ranging from 13.5% in 2008 to 12.3% in 2009 [1]. Current pressure sore detection methods are exclusively based on visual inspection and tend to pose a number of problems because skin change cannot be observed until skin damage has occurred. At this point in time, visual inspection is too late. Moreover, visual inspection of pressure sores on dark pigmented skin is even more challenging due to the inability to discern common bruises from actual physiological pressure sore activity [2]. A study on pressure sores in nursing homes has shown that black residents were more likely to have Stage 2-4 pressure sores than that of their white counterparts (who mostly had Stage 1 pressure sores) [2]. These findings can be directly correlated to the inability to accurately predict pressure sores on dark pigments. Pressure sores (Figure 1), also known as bed sores, form when prolonged pressure by bony structures in the body cuts off the blood supply and the tissue eventually dies. In effect, the pressure sore forms beneath the skin and as the sore progresses through the later development stages, it manifests in the form of lost skin. There is a need to monitor the sub-skin temperature change as pressure sores progress through the more critical stages. Microwave radiometry is a means to monitor the sub-skin temperature of pressure sores.

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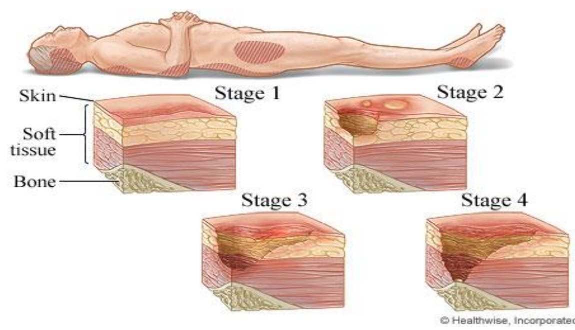

Fig. 1 – Stages of pressure sore development (Taken from WebMD)

II. Microwave Radiometry for Biomedical Sensing

Microwave radiometry is the measurement of emitted electromagnetic energy. This emitted energy can be related to an absolute temperature. For this project, this represents the detection of the thermal radiation emitted by the human body down to some plane wave power penetration depth.

The challenges that impede the realization of a handheld microwave thermometer/radiometer are outlined below:

- The antenna has to be well-matched and exceptionally efficient otherwise the brightness temperature will not be appropriately resolved.
- The frequency dependent losses and physical depths of the propagation medium must be accurately known or else the model for temperature extraction will not accurately depict actual biological medium.
- Outside interferences must be adequately isolated from the radiometer because EMI effects hinder the resolution of accurate subsurface temperatures.

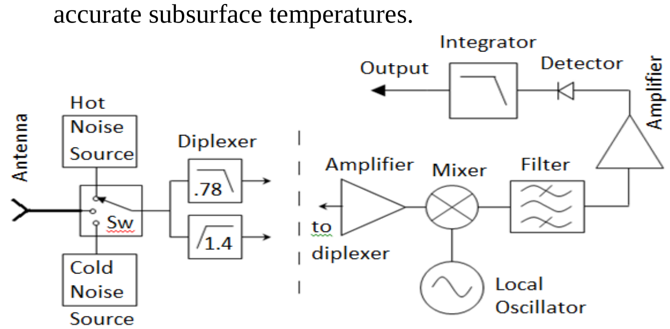

Fig. 2 – Dual frequency radiometer setup

The total power radiometer configuration (Figure 2) is chosen to perform brightness temperature measurements of a 3d-pressure sore phantom. The system is designed for both

0.73 - 0.83 GHz and 1.35 - 1.45 GHz frequency ranges with a theoretical temperature resolution of 0.1°C. Using the conventional definition, where the power has diminished to 37% (or 1/e) of the surface value, these design frequencies will ultimately detect thermal emissions from depths of ~29mm (0.78 GHz) and ~24mm (1.4 GHz) beneath the skin's surface for the setup shown in Figure 3. The application is similar to the radiometer found in [3]. A signal is detected from the antenna in contact with the phantom when the switch is positioned at the antenna port. This signal is then amplified, filtered for proper frequency selection, and next down converted for greater ease of post processing. Lastly, the signal is converted to a voltage and sent to a computer for post processing. The switch alternates from both a cold and hot calibration load. The temperature of the antenna is derived from a linear interpolation from the hot and cold load as shown in Figure 4. This interpolated temperature still has to be improved to account for the propagation effects within the body. A spiral antenna in contact with the human body is designed to have a return loss of ≥ 20dB for a frequency range of 0.73 to 2.1 GHz (Figure 5).

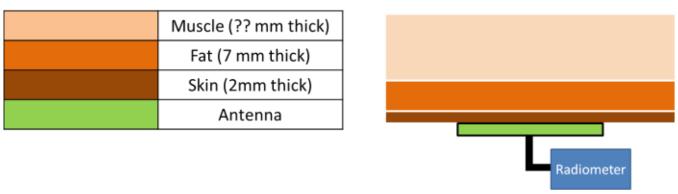

Fig. 3 – Depiction of radiometer in contact with the human body

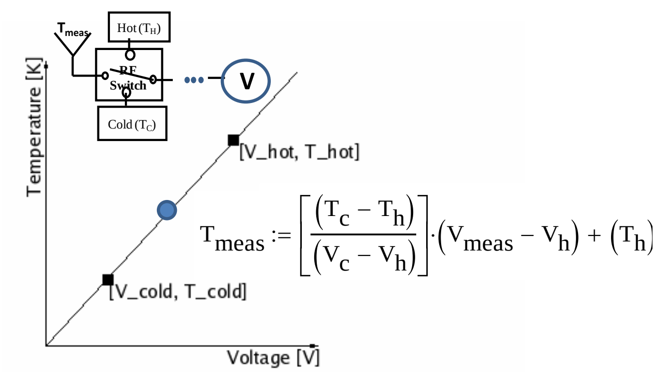

Fig. 4 – Calibration/system equation for radiometer (for temperature estimation)

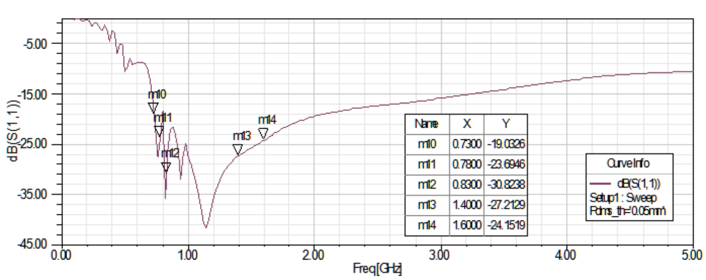

Fig. 5 – Return loss of spiral antenna in contact with the human body

Figure 6 highlights the temperature results from a 1.4 GHz radiometer measurement setup. Thermocouple probes are used to track the temperature changes from a stacked tissue phantom consisting of skin, fat, and muscle tissue mimicking materials. The muscle tissue mimicking liquid material is heated, placed on top of the skin and fat tissue, and then allowed to cool. The recorded thermocouple temperatures are compared to the extracted radiometer temperatures. As seen in Figure 6, the extracted radiometer temperature is closer in value to the temperature of the skin. This is evident because the dielectric constant of the skin and fat layers are higher than that of normal tissue, thus the penetration depth encompasses mostly just the effects from the fat and skin layers.

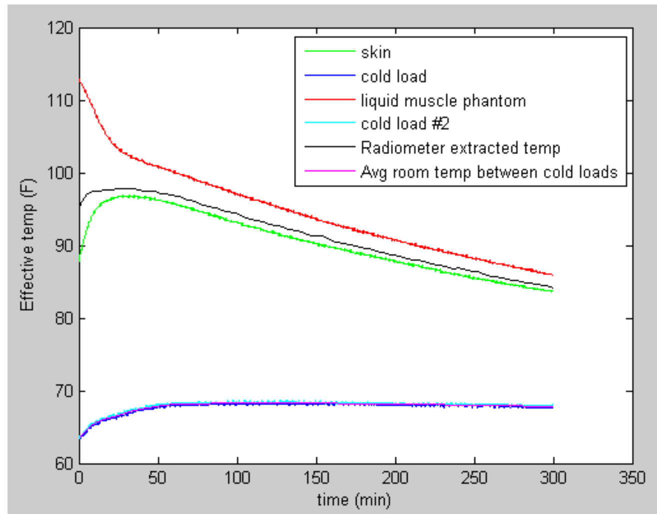

Fig. 6 – Extracted radiomter temepratures and recorded themocuple temperatures

III. Career Plans, Fellowship Impact, IMS Impressions

My immediate goals are to gain industry experience in the RF/MW field. Eventually, I plan to teach, conduct research, and become involved in diversity recruitment and retention at the collegiate level.

The impact that this fellowship has had on my growth has been immense. Not only has the financial support provided great monetary assistance, but I also have developed a strong desire to continually improve my grant writing skills. Winning a nationally recognized fellowship in my field has given me more confidence that I can continue to become more proficient at grant writing.

I have attended IMS 2012 in Montreal, Canada, 2014 in Tampa, FL., and 2015 in Phoenix, AZ. The experiences at IMS have definitely opened my eyes to the IEEE MTT-S community that I am a part of. I look forward to the future and growing with this community!

References

[1] US Department of Health & Human Services (Agency for Healthcare Research and Quality), "Pressure Ulcer Risk Assessment and Prevention: A Comparative Effectiveness Review," Jan 2012.

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