Active Millimeter-Wave Radar for Sensing and Imaging Through Dressing Materials

Amani Yousef Owda, Neil Salmon, David Andrews, and Nacer Ddine Rezgui

Dep. Electrical and Electronic Engineering, Manchester Metropolitan University, Manchester, United Kingdom

Email: Amani.owda@stu.mmu.ac.uk, n.salmon@mmu.ac.uk, david.andrews@mmu.ac.uk, n.rezgui@mmu.ac.uk

***Abstract*—A radar system is used to obtain information about the structure of dressing materials and hand support cast. The system is used also to assess the feasibility of using active radiation to penetrate dressing materials at different state (dry, wet and with cream) and provide information about the metal plate under the dressing. A comparison is made between the resolved structure of the samples from a pulse synthesis direct detection radar system that operates over the frequency band 15-40 GHz and the actual dimensions of the samples. Based on the results obtained, the authors suggest that active millimeter-wave imaging might be used as a non-contact technique for monitoring the wound healing under dressing materials without necessity of dressing removal.**

Keywords—active sensing; bandages; refractive index; dielectric permittivity; millimeter wave.

I. Introduction

In Radar, which is best known in security screening and remote sensing [1], the target object is illuminated by a coherent microwave source, and based on the reflected radiation from the target object the system can form an image. The line of sight distance between the Radar system and the target object or range R, can be measured through the round trip time T of the transmitted signal, the speed of the light c, and the refractive index n (where n=1 in vacuum), as shown in (1). A key figure of merit in Radar is the range resolution (the smallest distance between the targets at which they are resolved into separate targets) [2] and this is related to the bandwidth of the system BW, as illustrated in (2). The thickness of the sample d can be measured experimentally using the distance between two reflection peaks [3], as expressed in (3).

$$R=c*T/2n \quad (1)$$

$$\Delta R_s \geq c/(2n.BW) \quad (2)$$

$$d=R_2 - R_1= c*(T_2 -T_1)/2n \quad (3)$$

The millimeter-wave (MMW) band is the electromagnetic region between the microwave frequency band, and the terahertz frequency band and it covers the frequency band (30-300) GHz. Because electromagnetic radiation at microwave and MMW frequencies can propagate through typical dressing materials with little attenuation, these bands of the electromagnetic spectrum are promising for assessing bandaged wounds [4]. The transparency of bandages in the MMW region has led [5] to investigate using active MMW radiation to monitor wound healing under a plaster and a gypsum cast in contact with the human body. Currently visual inspection is the current protocol for monitoring the wound healing and this requires the removal of dressing layers, which can cause medical problems, be uncomfortable or painful to the patient [4]. Up-to-date there are no methods successfully assess the wound healing progress without removing dressing materials. A technique that could penetrate dressings and identify the healing status of wounds would be extremely beneficial, and therefore this paper aims to help assess the feasibility of using active MMW Radar to monitor wound healing in non-contact with the human body, by measuring the attenuating effect of bandages and creams, which are applied to cover the wounds.

II. EXPERIMENTAL SETUP

A. *Experimental Description*

A standard Ka-band horn antenna with a square aperture (46x46 mm^2) and nominal gain of 20 dBi over the frequency band (15-40) GHz was located ~ 250 mm from the sample under test (SUT) and was aligned in vertical polarization. As illustrated in Fig. 1, the antenna was connected through a high frequency cable to the vector network analyser (VNA). A large metal plate (length=1200 mm, and width 660 mm) was used as a background and also used for calibration purposes. A VNA with an operating frequency band (10 MHz-67 GHz) was used to illuminate the SUT and was connected to the computer though Ethernet cable and controlled via a Matlab program. The program allows the user to determine the start frequency (15 GHz), the end frequency (40 GHz), the number of data points (512), and the transmitted power level (1.6 mW); these parameters result in a range resolution 6.0 mm and bandwidth 25 GHz. The system was surrounded with absorbent foam material to minimise reflections from other objects in the lab and the data were saved directly to be processed later.

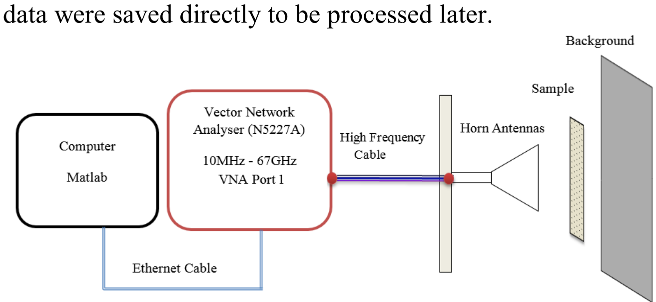

Fig. 1. Experimental setup for an active millimetre wave imaging system.

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B. *Methodology of Data Processing*

A mono-static radar system (transmitter and receiver are co-located) in Fig. 1 was utilised for measuring: A) the complex reflected signal (S_{11}) from the metal plate, B) the internal background signal measured with a microwave foam absorber target and C) the complex reflected signal from the sample under test. These particular measurements are selected as it enables calibration to be made quickly, before and after the measurements, thus minimising the effects of systematic errors. The foam absorber calibration measurements were used to subtract any internal reflected radiation, and the metal plate calibration measurement was used to remove the effect of transmitter and receiver response "dispersion" by de-convolution. The complex reflected signal for each sample (SUT, metal plate and foam absorber) were measured ten times and averaged at each frequency. The complex reflected signal in the frequency domain was transformed into time domain signal using the Inverse Fast Fourier Transform (IFFT). Zero padding was utilised beyond the measured 0-15 GHz frequency band to aid data interpretation. This methodology together with (1) and (3) was used to calculate the optical path length of the samples. The measured optical path length was compared with the actual path length of the sample that obtained using a standard ruler with ±0.5 mm absolute uncertainty.

III. RESULTS AND DISCUSSION

A. *Hand Support Cast Sample*

A hand cast made of plaster-of-Paris was located and aligned transversely between the horn antenna and the metal plate. The hand cast has a cylindrical tubular shape and dimensions (length 250 mm, and diameter 90 mm). Fig. 2 shows three reflection peaks associated with the hand cast and the metal plate; the first two peaks correspond to the reflections from the front and the back surfaces of the hand cast, whereas the third peak corresponds to the metal plate surface, as seen through the cast. Reflection peaks are produced in the time domain resulting from reflections from the surfaces of the sample or discontinuities in dielectric properties. The reduction of the third peak (~35%) compared to the value 1.0 obtained without the cast (see Fig. 3), is due to reflection and absorption by the cast material. The conversion between the time domain and the optical path length in free space was performed using (1). From the distance between two cast peaks ($d = R_2 - R_1$), the optical path length for the hand cast sample was measured to be ~85.5 mm, close (~4.5 mm) to the actual optical path length (90 mm).

B. *Gauze Burn Dressing Materials in Dry State*

A gauze burn bandage with ~10 mm thick was located and aligned between the horn antenna and the metal plate. The bandage was in dry state and removed from protective packaging prior to measurement. As illustrated in Fig. 3. The reflection from the gauze burn bandage is ~10%, compared with the reflection from the metal plate. Although, dressing materials are low loss materials, increasing the thickness of dressing materials increases the absorption and causes loss. The attenuation in the reflected radiation is measured by comparing the two reflection peaks that associated with the metal plate before and after locating the bandage. From the heights of the reflection peaks, the combined attenuation and reflection by the gauze burn bandage is estimated as ~10% for a 10 mm bandage thickness.

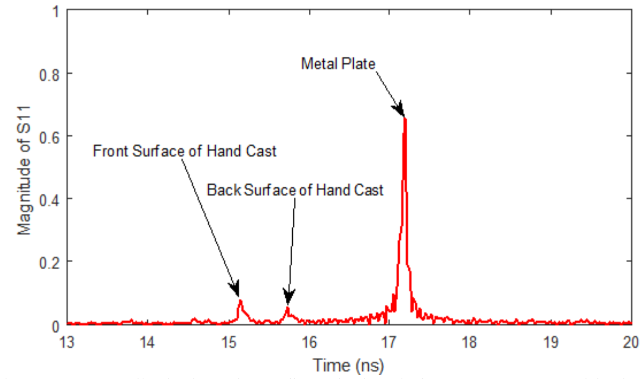

Fig. 2. Image displaying the reflected signal from a 90 mm wide hand cast located in free space between the horn antenna and the metal plate.

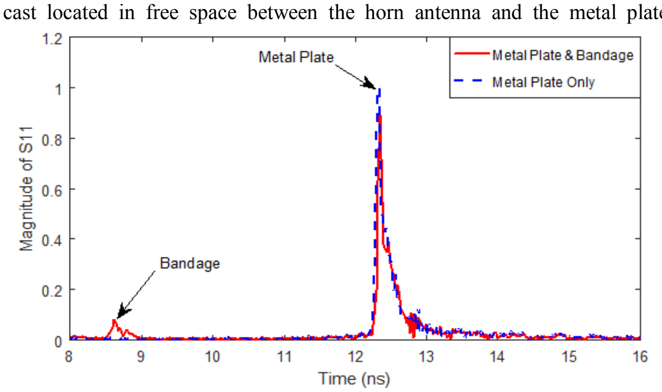

Fig. 3. Image displaying the reflected signal from a 10 mm thick bandage located in free space between the horn antenna and the metal plate. The solid red line shows the signal from the bandage and the metal plate and the broken blue line when the metal plate only is present.

C. *Gauze Burn Dressing Materials with Sudocrem*

Dressing materials are used widely on the treatments of injury and burn wounds. These materials are usually used with cream for avoiding friction between the skin and the dressing materials and for healing purposes. This section investigates the feasibility of using active radiation to sense different surfaces attached to the dressing materials and whether it is possible to sense features under these layers. A gauze burn bandage ~25 mm thick is attached to the metal plate and a thin layer of Sudocrem is attached directly to the front surface of the bandage; the complex reflected signal in frequency domain is transformed into a time domain signal using the Inverse Fast Fourier Transform (IFFT) and the result obtained is illustrated in Fig. 4. The results show two reflections peaks; the reflection from the cream and the front surface of the bandage is combined in peak 1, and the reflection from the back surface of the bandage and the metal plate is combined in peak 2. Although the imaging system can't resolve the cream layer attached to the bandage surface itself, this is doesn't mean that it can't sense the cream surface. The measured reflection from the front surface of the bandage in dry state did not exceed ~10% (see Fig. 2), whereas when a layer of Sudocrem is attached to the bandage the reflection is increased to ~16%. The optical path length of the bandage is measured to be ~ 27 mm from the distance between the two peaks. The difference between the actual path length and the measured path length is ~2.0 mm. It may be noted that although the metal plate seen through the cream layer has been reduced by a factor of 3, it is still possible to sense features under the cream layer.

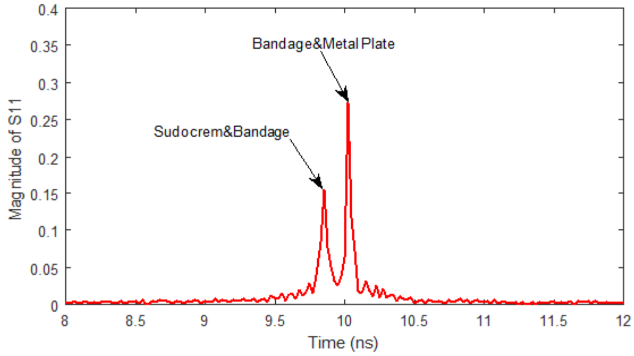

Fig. 4. Image displaying the reflected signal from a ~25 mm thick bandage with Sudocrem.

D. Gauze Burn Dressing Materials with Flamazine Cream

The results obtained with another ~10 mm bandage coated with a thin layer of a different cream Flamazine is illustrated in Fig. 5. The measurements show that, adding a layer of Flamazine cream increases the reflection of the front surface of the bandage from ~10% in dry state to ~30%. The signal passing through the cream and bandage and reflected from the metal plate is now 55%. The optical path length of the bandage in this case is measured to be ~9.5 mm using the distance between two peaks and (3). The difference between the actual path length and the measured path length is calculated to be ~0.5 mm.

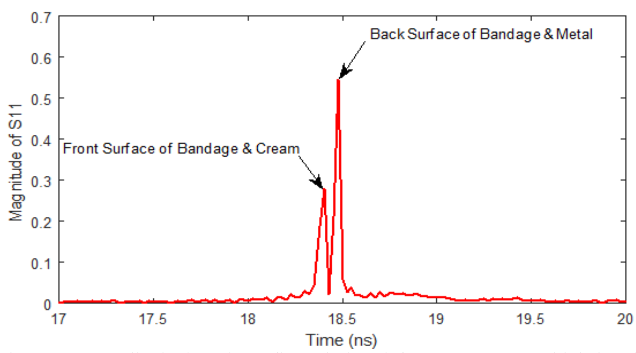

Fig. 5. Image displaying the reflected signal from a ~10 mm thick bandage coated with Flamazine cream.

E. Gauze Burn Dressing Materials with Water

The results obtained from ~10 mm wet bandage (bandage with water) is illustrated in Fig. 6. The bandage was attached directly with the metal plate and the results obtained show only one reflection peak since MMW radiation is highly absorbed in water [2]. The combined signal from reflection from the water in the bandage and that passing through the water and the bandage and reflected from the metal plate is now ~70%. This is higher than reflection from water alone (55%), so the attenuated reflected radiation from the plate may be estimated as ~15%. The metal plate seen through the wet bandage has been reduced by a factor of ~7. This means that it may still be possible to sense features under wet dressing materials.

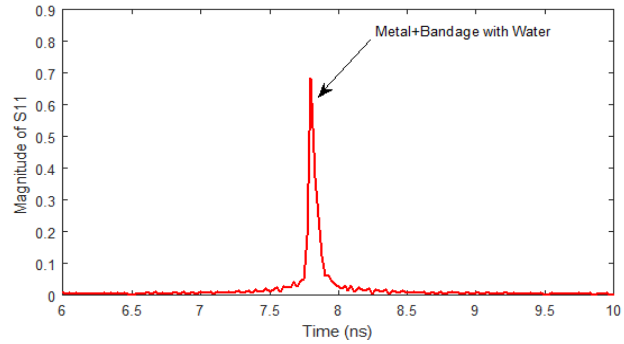

Fig. 6. Image showing the reflected signal from a ~10 mm thick wet bandage.

IV. Conclusion

Active millimetre wave Radar can provide precise information about the optical path length of the dressing materials and hand support cast (as in Fig. 2) and more importantly, it can penetrate the dressing materials and provide information about the metal plate under the dressing materials. Adding a cream layer to the bandages has a clear signature on the level of reflected radiation. This signature is based on the thickness of the cream layer and the dielectric properties of the cream as illustrated in Figs. 4 and 5. Millimetre wave radiation is highly absorbed with water and as a result, there is only a single reflection peak associated with wet dressing materials as illustrated in Fig. 6. The results obtained in this paper show that active millimetre wave Radar might be an efficient tool for monitoring the wound healing under dressing materials without their often-painful removal and in non-contact with the human body. In this paper, metal plate has been used a surrogate to the body surface and therefore, it is recommended that further measurements be made on human body or animals tissue to study the effect of wound size, exudates and cream layer.

References

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