Microwave Tomography for Hydration Assessment in Newborn Cattle: In Silico Proof of Concept

Brendon C. Besler* and Elise Fear
University of Calgary, Alberta, CA, T2N 1N4

Abstract

Dehydration is a leading cause of mortality in newborn cattle. While physical signs of dehydration are visible at 6% loss of body weight, diarrheal disease can quickly cause life-threatening dehydration. Tissue permittivity is proposed as a method of continuously monitoring hydration in calves. For an initial proof of concept, standard microwave tomography algorithms are applied to a realistic cross-section of a calf neck. A series of images are generated with permittivity perturbed to represent changes in hydration. The bulk permittivity is estimated using the average properties of the image and a close relationship between the reconstructed values and ground truth hydration permittivity is seen.

1. Introduction

Dehydration is a leading cause of mortality for newborn cattle in the United States [1]. Calves commonly contract infections that cause diarrhea. At body weight losses of 6%, calves begin to show outward signs of dehydration such as sunken eyes and increased skin tent duration [2]. However, diarrheal disease can escalate rapidly, becoming life-threatening at over 10% water loss [2]. Thus, there is demand for a method of continuous hydration monitoring to improve animal well-being and avoid costly veterinary interventions and animal loss.

Recently, tissue permittivity has been proposed as a means of monitoring hydration in humans [3]. Using a time-of-flight technique, microwave-based hydration assessment has been explored in simulation [3], in a group of athletes undergoing acute water loss [4], and a group of fasting volunteers [5]. This work presents an *in silico* proof of concept for applying standard microwave tomography techniques to monitor changes in tissue properties due to changes in hydration in calves.

2. Methods

2.1 Hydration Model

A two-dimensional transverse cross-section through the neck of a realistic bovine model (Biosphera, Brazil) is created as shown in Figure 1. Debye models are fit to the literature values of the tissues found in the neck [6] from 0.3 to 3 GHz. The following tissues are included in the neck model: skin, fat, muscle, tendon, cancellous bone, spinal cord, blood, esophagus, cartilage, air, thyroid, and lymph node. A linear hydration model, similar to [3], is applied to map changes in total body water to changes in permittivity. Specifically, the Debye permittivity parameters of each tissue are perturbed by the amount of water loss based on the tissue water content. The properties of the neck cross-section are updated for water loss from 0-6% of body weight and synthetic microwave scattering data are generated at each hydration level.

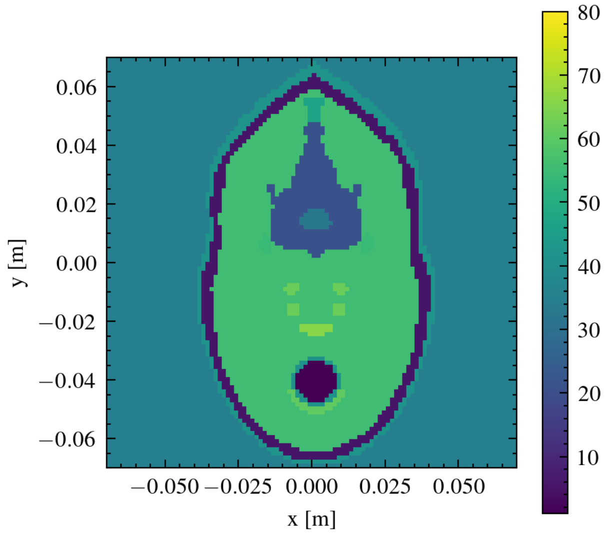

Figure 1. Relative permittivity of calf neck model.

2.2 Tomographic Approach

A conventional two-dimensional transverse magnetic microwave tomography approach is applied. 24 transmitters and receivers are placed on a circle of radius 0.1 m. The transmitters are modelled as infinite line sources. The forward solver is implemented using the conjugate gradient method implementation of Richmond's method [7]. Data are generated at 500 MHz and a background permittivity, $\varepsilon_r = 35 - j29$, representative of a glycerin-water mixture [8] is used. 1% white noise is added to the scattered field data. Inversion is accomplished using the Distorted Born Iterative Method (DBIM) with Tikhonov regularization [9]. The synthetic data are generated on a 0.14 m x 0.14 m (100 x 100) grid and the inversion is done on a 0.15 m x 0.15 m (60 x 60) grid. The

L-Curve method is applied to select the regularization parameter associated with the regularized least squares problem at each iteration [10]. To further regularize the problem, the regularized least squares solution is evaluated using the conjugate gradient method truncated at two iterations. The DBIM algorithm is terminated once the scattered field residuals increase or after 40 iterations.

The bulk permittivity of the neck is estimated using the average of the image and change is calculated relative to the nominal properties using:

$$\Delta\varepsilon = \frac{\bar{\varepsilon}_d - \bar{\varepsilon}_b}{\bar{\varepsilon}_b} \cdot 100 \quad (1)$$

where $\bar{\varepsilon}_d$ is the average reconstructed permittivity when dehydrated and $\bar{\varepsilon}_b$ is the average reconstructed baseline permittivity.

3. Results

The reconstructed scattered fields converge to within 10% of the synthetic data. Figure 2 shows the reconstructed permittivity of the neck cross-section at the nominal values. As can be seen, the large, high-contrast tissues of the neck are localized, and the permittivity estimate is reasonable. Because hydration influences the bulk properties of tissues, a low-resolution image is adequate for hydration assessment.

The relative change in permittivity for the actual model and reconstructed images is reported in Figure 3. As can be seen, the change in the reconstructed bulk permittivity closely follows the input permittivity.

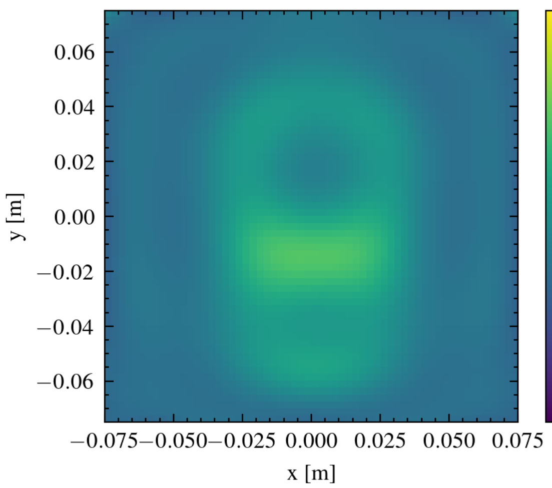

Figure 2. Reconstructed calf neck model relative permittivity at nominal hydration.

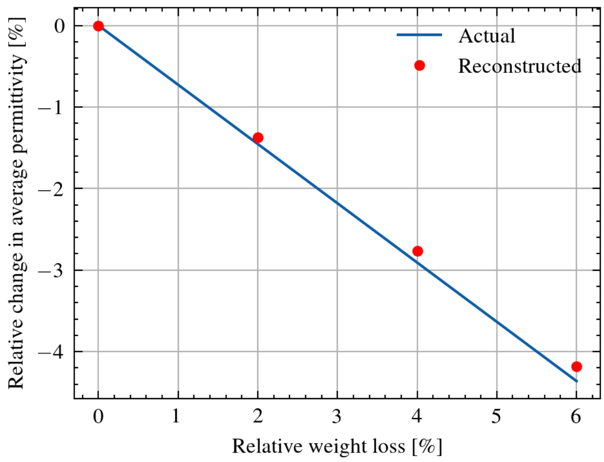

Figure 3. Change in relative permittivity due to change in total body water.

4. Conclusion

This work outlines the feasibility of using microwave tomography to assess changes in hydration in calves. Using standard microwave techniques and a model for changes in tissue properties due to hydration, the changes in the bulk properties of the neck are accurately assessed.

Further work includes considering the effect of salt-loss dehydration as caused by diarrhea on tissue properties, measuring the effect of hydration on excised animal tissues, and developing a practical microwave tomography system for calf hydration assessment.

6. Acknowledgements

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