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Microwave system to assess muscle quality using chained machine learning models

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Summary

A microwave system is currently in development with the goal of creating a standalone device capable of assessing muscle quality. This abstract presents a novel algorithm where three machine learning models are chained together in order to extract information from the muscle tissue without any measurements from supporting/competing techniques, like ultrasound.

1 Introduction

The Muscle Analyzer System (MAS) is a standalone microwave device currently being investigated as an alternative method to assess muscle quality [1, 2]. Today, the gold standard to assess muscle quality is the skeletal muscle index which is derived from a CT-scan at the third lumbar level. While accurate, this method is also expensive, not necessarily available everywhere and if it is available it used for a lot of examinations so time to access it can be limited. In previous studies A need for new methods to help in the diagnosis of sarcopenia, a skeletal muscle disorder, have been identified [3]. Therefore the MAS is being evaluated in its feasibility to be an alternative method to the current existing ones, such as CT and ultrasound.

2 Method

In the first iteration of the MAS a split-ring resonator was used as the sensor and although some differences were identified in the statistical analysis were found concerns over its penetration depth lead us to identify a different sensor [1]. Currently the primary sensor used for the MAS is a bandstop filter, that have been presented in depth in previous works [1, 2]. To continue evaluate the MAS new data have been collected via experiments using artificial tissue emulating (ATE) phantoms and from a study were healthy volunteers were measured. The difference between the new data and the data collected in previous works is that the new data is captured in a wider frequency range, from 1 MHz to 9 GHz, rather than 0.1–3 GHz.

In the case of the phantom experiments the skin, fat and muscle phantoms were placed on top of each other creating a simple three-layer model, where several different thicknesses is used for the skin and fat phantom. For the muscle phantom the dielectric properties is varied rather than the thickness. A person with poor muscle quality can have fat infiltration into the muscle tissue. Fat tissue has a much lower relative permittivity than muscle, at 2.45 GHz fat have ε_r of 5.2 and muscle of 52.4 [4]. So the fat infiltration into the muscle creates a contrast in the properties that could be identified by the MAS.

In the volunteer study the volunteers were measured mid thigh, one third of the distance from the superior patellar border to the anterior iliac spine. The thigh was chosen since it is considered a good indication of overall whole-body muscle quality [5]. To get a reference value, that are used to train the algorithm, ultrasound measurements were done in the same spot, measuring the skin and fat thickness as well as the cross-sectional area of the rectus femoris muscle.

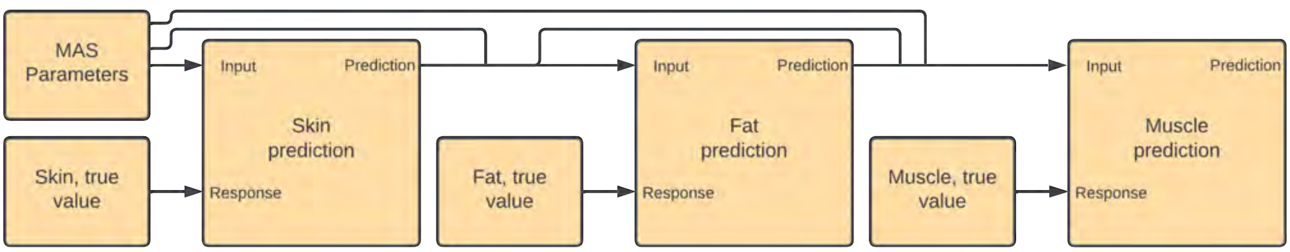

Figure 1. The 3-stage algorithm. The MAS parameters and the preceding tissue layers are used to train a model to quantify the tissue.

3 Algorithm

In order to get information from the muscle tissue, the microwave signal obviously needs to penetrate the skin and fat layers. So, the thickness of the skin and fat layers will impact the microwave signal reflected back to the sensor, therefore accurate information of their respective thicknesses is crucial. In Figure 1 a descriptive flowchart of the proposed algorithm is presented. The MAS parameters refers to the parameters derived from each microwave measurement, these include resonance frequencies, and the amplitude and quality factor of 3 dB of said resonances. Moreover, the phase is unwrapped and the slope of the unwrapped phase is the last of the MAS parameters.

The algorithm can be broken into three stages. The first stage uses the MAS parameters as its input to predict the skin thickness. The second stage again uses In each stage a machine learning model is trained using the known tissue information. Exactly what type of model is determined via an exhaustive analysis of multiple methods, doing hyperparameter optimization for each model, in order to determine the most suitable model for each stage. For each stage the best MAS parameters identified via the Kruskal-Wallis statistical test or a more extensive wrapper method that performs feature selection.

The purpose of the algorithm is to eliminate the need for measurements from other techniques like CT-scans or ultrasound, provided the models in each of the three stages are sufficiently accurate. Due to the nature of the data analyzing the phantom experiments is a classification problem and the volunteer study is a regression problem. However, the algorithm will work equally in either case.

4 Evaluation

The proposed algorithm is evaluated not only in terms of the accuracy score, in the case of the classification problem and R^2-score, in the case of the regression problem, but also using two variations of the algorithm. The first variation is to train the fat and muscle stages using the true value of the preceding stages rather than the predicted values. The second variation is to simply use only the MAS parameters to predict the fat and muscle information, so no preceding tissue information is passed to the second and third stages. In terms of Figure 1 the first variation can be viewed as the arrow not going from the "tissue prediction" box to the input but rather the "tissue, true value" box. The second variation is the case where only the MAS parameters go into the input of the prediction boxes.

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