Development of Na Adaptive Filter to Estimate the Percentage of Body Fat Based on Anthropometric Measures

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Abstract. This study aims to develop an algorithm of an adaptive filter to determine the percentage of body fat based on the use of anthropometric indicators in adolescents. Measurements such as body mass, height and waist circumference were collected for a better analysis. The development of this filter was based on the Wiener filter, used to produce an estimate of a random process. The Wiener filter minimizes the mean square error between the estimated random process and the desired process. The LMS algorithm was also studied for the development of the filter because it is important due to its simplicity and facility of computation. Excellent results were obtained with the filter developed, being these results analyzed and compared with the data collected.

1. Introduction

With the increase of obesity and sedentary lifestyles, the prevalences of diabetes and cardiovascular diseases are also rapidly increasing [1]. Obesity can be defined as excessive accumulation of body fat. It is about a complex public health problem that in the last decades has had its prevalence increased worldwide [2]. The period of highest risk for the incidence of obesity is the transition between adolescence and early adulthood, in both sexes and in various ethnic groups, as well as being a factor of important risk for cardiovascular diseases [3]. The Body Mass Index (BMI) is one of the most commonly used anthropometric indicators for being safe, easy to apply and inexpensive [4]. Waist circumference (WC) is an indicator of abdominal adiposity, which is often associated with the same obesity-related risk factors [5]. Although there is no consensus on the best anthropometric predictor of blood pressure levels high in the child and adolescent population, the importance of using simpler, more practical and cheaper cardiovascular risk [6]. According to the Ending Childhood Obesity report from the World Health Organization (WHO) (2016) [7], the number of overweight children in low-middle income countries more than doubled between 1990 and 2014, going from 7.5 to 15.5 million.
There are several methods used to evaluate body composition, especially body fat, in adults and adolescents. Among the indirect methods, hydrostatic weighing and dual energy X-ray absorptiometry (DEXA) stand out, however, they are more difficult methods to apply in clinical and epidemiological researchs and as a screening method in public health due to the high cost and the need for a qualified technical team to carry out the measures. Among the double indirect methods, anthropometry is considered a simple, fast and low-cost method that can be applied in a large number of individuals. Many anthropometric indicators have been proposed to diagnose health risks by taking into consideration the increase of body fat. The most widely used is still the body mass index (BMI), which, however, has some limitations [8]. With a tendency to persist in adult life, it is necessary to establish the best indicator of distribution of body fat that allows early identification of adolescents to establish interventions and improve future cardiovascular health [9].

Therefore, it is of great importance to construct techniques for tracking and / or screening of the percentage of body fat, based on the analysis of low-cost and non-invasive indicators, such as anthropometric parameters (weight, height, waist circumference, among others) that are one of the best health indicators in the juvenile population [10], being universally applicable, with good acceptance of the population and proposed by the World Health Organization. Adaptive filters are interesting in cases where some of the characteristics of the application are not known. Thus, it can be said that adaptive filters are best suited for applications where the input signal conditions or the system parameters vary slowly and the filter is capable of self-tuning to compensate such changes. The classic algorithm LMS (Least Mean Squares) is one of the most known techniques for the development of an adaptive filter. The LMS uses a stochastic gradient algorithm to adapt the load of a filter. This adaptation consists in the continuous (and adaptive) adjustment of the values of the filter coefficients, taking as a measure the minimization of the error in the mean of the squares. Therefore, the objective is to implement an adaptive filter, based on the Wiener technique, that can infer the percentage of body fat of adolescents by noninvasive measures.

2. Methods

2.1 Sampling
The sample was obtained from the school population of 16 schools in the public school network of Sao Luis, Maranhao, Brazil. The schools were chosen at random. The sample consisted of 471 students, being 329 female and 142 male, aged 10 to 19 years. The following exclusion criteria were adopted: Female adolescents who were pregnant, breastfeeding or using contraceptives; Physical incapacity that would preclude or compromise anthropometric measures; Non-agreement of the responsible ones or of the participants; Absence in data collection. The present study is approved by the research ethics committee of the University Hospital of the Federal University of Maranhão, according to opinion 251/11.

2.2 Data collection
The admeasurement of all variables was performed by trained researchers using standardized techniques and calibrated equipment. All measurements were made in duplicate and the mean was considered in the data analysis. The following variables were collected: weight, height, waist circumference and percentage of body fat that was obtained through the Tetrapolar Bioimpedance apparatus (Sanny, Brazil). From the information obtained by the collected variables, a matrix X, of order 4 x 471 was generated, with the values of x1, x2, x3 and x4, respectively, weight, height, waist circumference and percentage of body fat that was obtained. The matrix description can be seen as follows:

\[
X = \begin{bmatrix}
x_1(1), \cdots, x_1(n), \cdots, x_1(N) \\
x_2(1), \cdots, x_2(n), \cdots, x_2(N) \\
x_3(1), \cdots, x_3(n), \cdots, x_3(N) \\
x_4(1), \cdots, x_4(n), \cdots, x_4(N)
\end{bmatrix}
\]
Where \(1 \leq n \leq N\).

The measurement of all information was collected by trained individuals to use calibrated equipment.

2.3 Wiener filter

The Wiener filter is considered one of the best linear least squares filters that can be used for prediction, estimation, interpolation, signal and noise filtering, etc. To design them, an appropriate prior knowledge of the statistical properties of the input signal is required. The problem is that this knowledge usually cannot be obtained. The objective of the Wiener filtering is to determine the impulse response of length \(N\), having \(u(n)\) as input and given that the output of the filter is \(y(n)\). Then, we get the error signal \(e(n)\) from subtraction of the desired signal \(d(n)\) by \(y(n)\) as shown in the following equation:

\[
e(n) = d(n) - y(n)
\]

(2)

In order to minimize the error signal \(e(n)\), we must choose the coefficients of the filter with the purpose to match \(y(n)\) to \(d(n)\). Thus, the function to be minimized as mean square error, is given by the following expression:

\[
J = E[e(n)^2] = E[e(n)e^*(n)]
\]

(3)

Where \(J\) is the cost function to be minimized.

To minimize the cost function \(J\) is given a vector \(w = [w0, w1, \ldots, wN-1]^T\) satisfying equation (3).

\[
y(n) = w^H u(n)
\]

(4)

Then we have from equation 4, the error signal expressed as:

\[
e(n) = d(n) - w^H u(n)
\]

(5)

Substituting equation 5 into equation 3 we obtain:

\[
J = E[|d(n)|^2] - p^H w - w^H p + w^H R w
\]

(6)

Where \(R\) is the input autocorrelation matrix, \(p\) is the vector composed of the cross correlation between the desired response and the input components. Thus, we can describe in the following matrix form:

\[
R = \begin{bmatrix}
R_x[0] & R_x[1] & \cdots & R_x[N-1] \\
R_x[1] & R_x[0] & \cdots & R_x[N-2] \\
R_x[2] & R_x[1] & \cdots & R_x[N-3] \\
\vdots & \vdots & \ddots & \vdots \\
R_x[N-1] & R_x[N-2] & \cdots & R_x[0]
\end{bmatrix}
\]

(7)

\[
p = \begin{bmatrix}
p[0] \\
p[1] \\
p[2] \\
\vdots \\
p[N-1]
\end{bmatrix}
\]

(8)

To find the coefficients of the filter \(w\), we calculate the gradient of \(J\), deriving and equating the equation to zero.

\[
\Delta J = \frac{\partial J}{\partial w} = 2p - 2Rw
\]

(9)

Therefore, obtaining the following result:
\[ R w_0 = p \]  
\[ w_0 = R^{-1} p \]  
(10)  

(11)

Being \( w_0 \) the vector of optimal coefficients for the Wiener filter. From equation 6, we can determine the minimum mean quadratic error as follows:

\[ J_{\text{min}} = E [ |d(n)|^2 ] - p^H w_0 - w_0^H p + w_0^H R w_0 \]  
(12)

Substituting \( w_0 \) by equation 11 we will get:

\[ J_{\text{min}} = E [ |d(n)|^2 ] - p^H R^{-1} p - (R^{-1} p)^H p + (R^{-1} p)^H R R^{-1} p \]

\[ = \sigma_d^2 - p^H R^{-1} p \]  
(13)

Where \( e_k = y_k - w^T k X_k \).

2.4 Correlation coefficient

It is often necessary to study the relationship between two or more variables. If the study deals with only two variables, we have a correlation and a simple regression. If we involve more than two variables, we have multiple correlation and regression. Regression and correlation deal only with the linear relationship between two variables. The correlation analysis provides a number that summarizes the degree of linear relationship between the two variables. That is, the correlation coefficient is adequate to evaluate only the linear relationship. The two variables may be perfectly related, but if it is not in a linear form, the value of the coefficient can be zero or close to zero. The correlation coefficient can vary between -1 and +1, with a coefficient of +1, indicating a perfect positive linear correlation. A correlation coefficient of -1 indicates negative perfect linear correlation. The most common is that the coefficient is in the interval between these two values. A correlation coefficient of 0 (zero) means that there is no linear relation between the two variables.

3. Results

When executing the developed algorithm, with the matrix \( X \) created in item "C", we define a new matrix \( Z \) that will be the input of an adaptive filter whose output will be a vector \( y_1 \) of dimension 1x471. From vector \( y_1 \), a new matrix \( Z_2 \) is generated, and it contains the time delay determined by another algorithm that assists in the execution of this one. This delay identifies at which sampling position there is the best correlation index between the input matrix and the desired result. We can see in figure 1 below, the result of the delay and the correlation coefficient in relation to the matrix input of X:

![Figure 1](image-url)  

**Figure 1** - Graph of the result of the coefficient correlation and the delay determined by the matrix X.

We can verify through figure 1 that the X axis is the input matrix of the sampling giving its maximum value of 471, and the Y axis being the result of the correlation coefficient in approaching
the value +1. This shows, therefore, that the correlation result reached its expected maximum value.
To make sure that the correlation coefficient was within the characteristics of its basic assumption, we
generated the graph between the percentage of body fat and the adaptive measure obtained by the filter.
Figure 2 below shows the generated graph:

![Figure 2 - Relationship between fat percentage and Measurement obtained.](image)

We see that the relationship between the two variables meets the basic assumption of correlation
coefficient, being them linear variables and perfectly related. With the matrices created and knowing
the determination of the delay, and that the correlation coefficient is within the expected
characteristics, we obtained the following result for our sample of the 471 students:

![Figure 3 - Relation of the percentage of calculated body fat and that stimulated by the adaptive filter.](image)

We can see in figure 3 the comparison between the information of Body Fat Percentage that had
already been calculated - in blue color - and the result of the Body Fat Percentage stimulated by the
developed filter - in Yellow color - that there were few divergences

4. Conclusion
The Wiener Adaptive Filter developed in this study proved to be efficient when executed and in
showing the correlation result of coefficients of the defined matrices. The prevalence of overweight
and obesity has increased significantly in recent decades, and is associated with the development of
cardiovascular diseases and metabolic disorders, such as diabetes and hypertension, both in adults and
children and adolescents. The anthropometric indicators, which are weight, height and waist circumference, are the most used indicators in clinical practice and in epidemiological studies to identify / evaluate overweight / obese individuals with a high risk of developing cardiovascular problems. Hence, the algorithm developed in this work may aid in the screening of individuals with high body fat percentage and thus, help in the prevention of comorbidities associated with overweight. The use of the filter developed in the present study by health professionals will be of great assistance since it will allow the analysis of the patient's body fat percentage through low cost, reproducible and accessible indicators. This will allow the screening of overweight and obese patients serving as a method of prevention for possible comorbidities associated with being overweight, since the filter will allow the early intervention of these adolescents.

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