PDA BASED BODY FAT MEASUREMENT SYSTEM

Mi-hee Lee, Hyoung-Ki Lee, Seokwon Bang , Yongbeom Lee and Sangryong Kim

Interaction Laboratory, Digital Research Center, Samsung Advanced Institute of Technology, Kiheung, Korea

e-mail: [mh4.lee, twinclee, banggar.bang,1eey, srkim]@samsung.com

Abstract: The purpose of this study is a development of PDA(Personal Digital Assistance) based body fat measurement system. Bioelectrical impedance method is used for measuring human body composition. The method is based upon the principle, which demonstrates the electrical conductivity of fat-free mass (FFM) is far greater than that of the fat. Linear regression equation for PDA based body fat measurement is derived from the result of bioelectrical impedance. The subjects are 126 healthy males aged 30.3±9.6 yr (mean±SD) and 108 healthy females aged 30.3±10.9 yr. Bioelectrical impedance is measured for each subject with arms straight out. The arms are lifted forward at 90 degree angle to the body. Two electrical impedance analyzers ((HBF-302) and Health monitor (PDA based)) compute bioelectrical impedance with four electrodes. As a result, the best-fitting regression equation for predicting percent body fat is found out, which consist of $10^6/R^2$ and $(10^6 \times H^2)/R^2$. These results suggest that bioelectrical impedance measurement is a useful measure of percent body fat in portable device as PDA.

Introduction

Recently while people are having a growing interest in health issue, many programs about healthy life are shown in TV. These programs represent people's significant concern over their health. The contemporaries strive for managing wholesome body with effort. The concerning over one's own health comes into prominence not only in Korea, but also in Japan, U.S, and Europe. Diet becomes very important issue to both men and women. However, it is not always beneficial to lose a weight through a diet. Losing weight through musculature diminution can be even harmful to the body. The diet is only beneficial when body fat decreases. There are many types of body fat measurement systems in the market, but those systems have problems with portability. Since PDA(Personal Digital Assistance) Phone based body fat measurement system takes an advantage in portability from its size, an user is able to measure his or her body fat in any location anytime. Thus, the merit about size and portability is expected to satisfy needs of people who has significant interest in own health information. Actual measurement of body fat is required to check obesity, but there is simple method only need few personal data (ex: height, weight etc…), which indicates obesity level [1]. However, this method has a drawback to measure muscle and body fat. Therefore, Segmental Bioelectrical Impedance Analysis is used in these days. This method measure impedance in each part of body, and analyze body component to check body fat and lean body mass [2-3].

Segmental Bioelectrical Impedance Analysis is a technological method, which is measuring total body water [4]. Since LBM (Lean Body Mass) contain a certain amount of water, BIA is used to compute LBM in a human body. Let the remainder value be considered as body fat when LBM is subtracted from body weight. Then BIA calculates percent body fat through dividing body fat by weight. BIA have been used since Hoffer[4]'s report in 1969 for body composition analysis. In 1980s, many researchers including Lukaski [5], Kushner [6], Segal [7] performed experiment with healthy persons to confirm appropriateness of BIA. Afterward, BIA has been researched to distinguish patient of obesity[8] and unbalanced nutrition[9]. Besides, BIA is studied for measuring total body water[12]. Since BIA is widely used, NIH (National Institutes of Health) held a comprehensive conference and conduct a forum to discuss accuracy, problem, application, and standardization of BIA[13]. BIA has been developing from single frequencies BIA method to multi frequencies BIA method. Also, whole body BIA method, which measures the impedance of the whole body is changing into segmental BIA method which measures the impedance of each body part[3].

In this study, regarding convenience, cost and accuracy of measurement, segmental BIA measurements are performed using four electrodes, which calculate body fat from electric resistance of body is used. The system consists of sensing part and PDA phone part. The sensor part measure Bio-impedance. PDA phone part receives Bio-impedance value from sensor part through infrared ray, then calculates LBM and body fat based on the Bio-impedance value. Since a regression equation, which measure LBM depends on measuring sensor, we concentrate on figuring out a regression equation model that appropriates to measure body fat with PDA phone based system.

ISSN: 1727-1983

Materials and Methods

The system is comprised of measure module part and S/W part. The module part receives Bio-impedance signal from a subject. The signal is amplified and processed to engage with PDA. The S/W part applies the received signal to body fat calculation algorithm, then display a result through GUI (Graphic User Interface). Measuring module is built with light weight so that subject is able to equip and check corporal information anytime. Software is developed using eMbeded Visual C++ 3.0. eMbeded Visual C++ 3.0 is based on pocket PC 2002, which is most popular tool among PDA based OS.

Sensing Module

In this study, the body fat measuring system is developed, which is focused on portable measuring instrument. Thus, it is designed compact and light to maximize portability[Figure1]. Research about examination of component specification and optimized operation are preceded for accurate and stable measurement. Furthermore, the system focused on optimized component arrangement and low power consumption for portable device. These two technical points are applied from circuit design. The specification is in [Table1], and the block diagram is in [Figure 2].

Figure 1: External view of measurement sensor
① Touch electrodes: The part that is held with index finger and thumb ② Infrared ray transmission part: The part that transmit a result to PDA ③ LED signal: showing operating condition ④ Power/transmission: on/off, button that transmit that to PDA

The user direction of Bio-impedance measurement is following.

1. Push the power button of the system
2. When the green light blinks, hold the sensor lightly with point finger and thumb [Figure 3-a].
3. Straight arms in 90 degrees to the body and maintain a measuring position. Then, sensor applies 50 kHz sine wave with 0.3mA constant current for 3 seconds to measure the bio-impedance. During the measuring process, do not bend the arms or move the body.
When green light blinks: ready for measurement.
When green light stops blinking: measurement finished
When red light blinks: measurement over time or measurement error
4. Place infrared ray port of measurement part and PDA facing each other[3-a]
5. Make the distance between measurement part and PDA less than 30cm and send the data[3-b].
6. Press the power button and a result of the body fat measurement would be displayed with tone.

Table 1: Bio-impedance measurement sensor spec.

Size	110 mm X 38 mm X 20 mm
Voltage	6V (2 Mercury batteries are used
Current Consumtion	standby : < 1 uA body fat measurement: 25mA (Peak value)
Transmission with PDA	Infrared ray transmission (IrDA)
OS	Pocket PC 2002
Application S/W	1M byte (1K byte, Algorithm only)
sensor	4 Bio impedance measurement electrodes
Measurement signal	Bio impedance
accuracy	Over than 98% accuracy compare to world best product

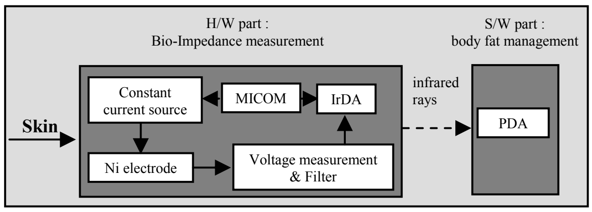

Figure2: The block diagram for the body fat measurement system

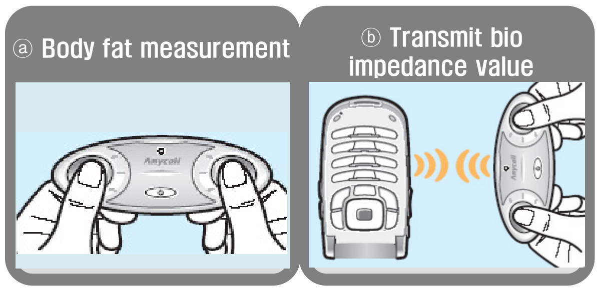

Figure 3: Percent body fat measurement

Measurement and managing software

The PDA phone used in S/W development is Mits (model No: M400), which have Pocket PC OS. Once PDA receives the bio-impedance through infrared ray from the sensor, it computes a percent body fat and LBM using Regression equation. It is possible to manage personal health history because, the system enables a user to input or select their data before a measurement. The system also supports a useful information for managing body fat.

ISSN: 1727-1983 © 2005 IFMBE

Regression equation optimize for LBM measurement

The subjects are 234 males and females with ages of 15~50. The collected experiment data is diverse, which is shown in their BMI(Body Mass Index: weight/height^2). Since a percent body water can cause a drastic change in percent body fat measurement, all the subjects are not allowed to exercise or drink any beverages for 24 hours before the experiment. The survey is given to the subjects to have a data about their medical history, and the subjects who have a drastic change of weight are exempted from the experiment. A body fat measurement by Bioelectrical Impedance Analysis is preceded with following step. First, straight both arm in 90 degrees to the body[Figure 3].

Then hold 4 sensors with index finger and thumb, and the system applies 50Hz high frequency with 0.3mA constant current to upper part of body. Finally, the system measures the impedance of the body. After 3 seconds subject input personal data including sex, age, height, and weight, the output of percent body fat is calculated based on the regression equation of height, weight, body impedance and other variables.

Lukaski discovered that the correlation coefficient of Fat Free Mass and $height^2$/impedance is 0.98 and the correlation coefficient of Fat Free Mass and weight is 0.91. It shows that $height^2$/impedance and weight are the most important variables to calculate Fat Free Mass. Once Fat Free Mass is calculated, it is easy to compute Percent body fat. However, it is not possible to estimate the correct percent body fat with only those two variables when the PDA phone based body fat measurement system is used. Therefore, the new regression equation for estimating Fat Free Mass needs to be derived using various DBs. Thus, residual is analyzed with HBF-302(OMRON, Japan) in the same method as the PDA phone based body fat measurement system.

Then, the result of HBF-302 is compared with the result of the PDA phone based body fat measurement system to prove the correctness of percent body fat by the BIA method. The optimum regression model (Eq. 1) is comprised of FFM regression model from patents and papers of the inside and outside of the country and optimum variables from the estimated data and t-test.

FFM (Fat-Free Mass) optimized regression model:

$$F = C_1H^2 - C_2R + C_3W + C_4A + C_5S + C_6$$

C_1-C_6: coefficient, H: height, R: resistance, W: weight, A: age. S: sex

The Fat Free Mass estimating function (eq. 2) is comprised of the optimum values for each coefficient. They were obtained from the estimated value of the PDA phone body fat measurement using the FFM optimized regression model and residual analysis of estimated Fat Free Mass by HBF-302(OMRON, Japan).

FFM(Fat-Free Mass)regression equation:

$$f = 0.0008135H^2 - 0.014R + 0.460W - 0.0746A - 2.346S + 10.469$$

H: Height(cm), R: Resistance(ohm) , W: weight(kg) , A: age , S: sex(male=0, female=1)

While all the values of p were less than or equal to 0.05, the predicted R-Sq had a very low value, which was 94.9%. On the other hand, Graph 2 shows that Fat Free Mass residual has a very high value, which is ±3kg. Thus the new variable needs to be proposed for the new regression model. However, though the regression model was analyzed several times with different variable, the standard deviation of residual was still big. Therefore, different regression equations are required for different genders and ages. The original regression equation is divided into six different regression equations. The optimum values for each coefficient and each equation are obtained by using the MINITAB DOE(Design of Experiments) which are the Analyze factorial design, the Contour plot, and the Response Optimizer.

Gender: Male, Age : 10 ~ 16

$$f = 0.000587\times H^2 + (-2.761\times 10^6)/(R-23.091)^2 + 0.0002813\times 10^6H^2/(R-23.091)^2 + 0.0094R + 0.443W - 12.75$$

Gender: Female, Age : 10 ~ 16

$$f = 0.0004905\times H^2 + (-2.255\times 10^6)/(R-23.091)^2 + 0.0002276\times 10^6H^2/(R-23.091)^2 + 0.0001047R + 0.349W - 5.339$$

Gender: Male, Age : 17 ~ 18

$$f = 0.0005802\times H^2 + (-2.682\times 10^6)/(R-23.091)^2 + 0.000277\times 10^6H^2/(R-23.091)^2 + 0.006975R + 0.371W - 6.05806$$

Gender: Female, Age : 17 ~ 18

$$f = 0.0004867\times H^2 + (-2.261\times 10^6)/(R-23.091)^2 + 0.0002266\times 10^6H^2/(R-23.091)^2 + 0.0026R + 0.299W + 8.1$$

Gender: Male, Age : 19 ~ 50

$$f = 0.0005742\times H^2 + (-2.666\times 10^6)/(R-23.091)^2 + 0.0002688\times 10^6H^2/(R-23.091)^2 + 0.00369R + 0.3W - 0.009A + 3.149794$$

Gender: Female, Age : 19 ~ 50

$$f = 0.0004871\times H^2 + (-2.286\times 10^6)/(R-23.091)^2 + 0.0002250\times 10^6H^2/(R-23.091)^2 - 0.0054R + 0.25W - 0.068A + 14.7057$$

Results

The body fat of 39 males and females were recollected and calculated using the FFM regression equation in the PDA phone based body fat measurement system. The equation was optimized for different genders and ages. The histogram of the Fat Free Mass standard deviation analysis shows that the average error is 0.56 and the standard deviation is 0.43. The analysis result of the Fat Free Mass residual using the optimized regression equation. It tells that the residual is normal distributed from -0.8943kg to 0.9925kg in 95% confidence interval. The result that the residual is normal distributed and from -1.4693% to -1.2647% in 9 % confidence interval. As a result, when the driven regression is applied to the PDA phone based body fat measurement of this research, it showed 98.41% correct compared to HBF-302(correctness 100%, OMRON, Japan)

Conclusions

Body fat measurements have been developed in several different methods inside and outside of the country. However, it is the first Mobile Phone based body fat measurement system. Additionally, since Bio-impedance measuring sensor is separate from percent body fat management system, there are an unlimited number of fields to apply this method. For example, if the body impedance is estimated and sent to the refrigerator that has a SW for measuring and managing body fat through infrared ray, it would be possible to display the body fat information and the diet information on the refrigerator.

Also, PDA and PDA phone is currently the most favored device because of the improved functionality of the processor and the modularity of the unit. Since the application is developed based on Pocket PC 2002 that is most popular OS for PDAs, using eMbeded Visual C++ 3.0 would be easy to develop SW for Portable Devices. Also, it would be easy to combine the method with other compact body measurement systems.

References

[1] Roche, A.F., Siervogel, M., Chumlea, W.C., Webb, P., "Grading body fatness from limited anthropometric data." *American Journal of Clinical Nutrition,* 34:2831-2838, 1981.

[2] Lukaski, H.C., Bolonchuk, W.W., Hall, C.B., Siders, W.A., "Validation of tetrapolar bioelectrical impedance method to assess human body composition." *Journal of Applied Physiology,* 60:1327-1332, 1986.

[3] Cha, K., Chertow, G.M., Gonzalez, J., Lazarus, J.M., Wilmore, D.W., "Multi-frequency bioelectrical impedance estimates the distribution of body water." *Journal of Applied Physiology*, 79:1316-1319, 1996.

[4] Hoffer, E.C., Meador, C.K., Simpson, D.C., "Correlation of whole body impedance with total body water volume." *Journal of Applied Physiology*, 27: 531-534, 1969.

[5] Lukaski, H.c., Bolonchuk, W.W., "Estimation of body fluid volumes using tetrapolar bioelectrical impedance measurement." *Aviat Space Environ Med*, 59:1163-1169, 1988.

[6] Kushner, R.F., Schoeller, D.A., "Estimation of total body water by bioelectrical impedance analysis." *American Journal of Clinical Nutrition,* 44:417-424, 1986.

[7] Segal, K.R., Gutin, B. Prestal, E., Wang, J., Van, T.B., Estimation of human body composition by electrical impedance methods: comparative study." *Journal of Applied Physiology*, 58:1565-1571, 1985

[8] Houtooper, L.B., Lohman, T.G., Going, S.B., Howell, W.H., "why bioelectrical impedance analysis should be used for estimating adiposity." *American Journal of Clinical Nutrition,* 64:436-448, 1996.

[9] Chertow, G.M., Lowrie, E.G., Wilmore, D.W., Gonzalez, J., Lew, N.L., "Nutritional assessment with bioelectrical impedance analysis in maintenance of hemodialysis patient." *Journal of the American Society of Nephrology*, 6:75-81, 1995.

[10] Fredix, E.W.H.M., Saris, W.H.M., Soeters, P.B., Wouters, E.F.M., "Estimation of body composition by bioelectrical impedance in cancer patients." *European Journal of Clinical Nutrition*, 44:749-572, 1990.

[11] Kotler, D.P., Tierney, A.R., Wang, J., Pierson, R., "Magnitude of body cell-mass depletion and the timing of death from wasting in AIDS." *American Journal of Clinical Nutrition*, 50:444-447, 1989.

[12] Meguid, M.M., Lukaski, H.C., Tripp, M.D., Rosenburg, J.M., Parker, F.B.P., "Rapid bedside method to assess changes in postoperative fluid status with bioelectrical impedance analysis." *Surgery St Louis*, 112:502-508, 1992.

[13] Kushner, R.F., Gudivaka, R. Schoeller, D.A., "Clinical characteristics influencing bioelectrical impedance analysis measurement." *American Journal of Clinical Nutrition,* 64: 423-427, 1996.

[14] Thomasset, A., "Bio-electrical proerties of the impedance measurement." *Lyon Med.*, 207, 107-118, 1962.

ISSN: 1727-1983 © 2005 IFMBE