

# A Fuzzy Logic Approach to Predict Human Body Weight Based on AR Model

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**Abstract**—This paper proposes a body weight prediction method using autoregressive (AR) model and Fuzzy-AR model. First, we employ 6 persons body weight change data of 365 days. AR model predicts body weight of a day from these time-series data. We calculate an order of AR model for each person by Akaike's Information Criterion. In the experiment, we predicted body weight change of next day for those subjects. The AR model obtained 0.798 in correlation coefficient between predicted and truth values. Second, we propose a Fuzzy-AR model that predicts body weight of next  $p$  days from last  $p$  days, where  $p$  is the order of AR model. In this method, we propose a Fuzzy-AR model with the fuzzy membership function using last  $p$  days data. In the experiment, the Fuzzy-AR model obtained 0.558 in correlation coefficient on 2 subjects.

**Keywords**- healthcare system; autoregressive model; prediction model; time-series data; body weight.

## I. INTRODUCTION

Generally, the health care system provides healthcare services, including screening examinations, prenatal care and infectious disease control. Currently, busy lifestyles including hard work in daily business rise in chronic disease. In this situation, health care system for healthy people receives much considerable attentions. Reference [1] pointed that “More than 1 billion people in the world are overweight, and at least 300 million of those are clinically obese. Without action, more than 1.5 billion people are expected to be overweight by 2015.” Thus, human body weight control is very important in the world.

In this paper, we consider a personal telehealth system to control body weight of the individual. In this system, it collects the daily weight data and analyzes them. It finally gives an advice to control it. In Ref. [1], this system is the following goal, i.e., “Empower individuals and patients to better manage their health by providing them with information regarding their fitness and health through personal medical devices and services.”

In this paper, we propose a prediction method of body weight of next day using autoregressive (AR) model [2]-[4]. Next, we predict body weight change for next plural days using Fuzzy-AR model [5]-[8]. Thus, we predict body weight change

using AR model and Fuzzy-AR model. We employ 6 subjects the body weight change data. The 6 subjects of AR parameters are calculated from Yule-Walker equation, and the order of AR model is determined by Akaike's Information Criterion. As the result, the correlation coefficient between the predicted and truth values is 0.798 on the 6 subjects. Next, using the order of AR model, we find the cycle of body weight change. The cycle is used as the order,  $p$ , of the Fuzzy-AR model proposed here. Fuzzy-AR model with fuzzy membership function predicts body weights of next  $p$  days from the time-series data of last  $p$  days. We compare the prediction accuracy using AR model with that using Fuzzy-AR model. As the result, Fuzzy-AR model obtained higher correlation coefficient.

## II. PREDICTION METHOD BY AR MODEL

We predict body weight change of a day by AR model. The AR model is defined by (1).

$$y(t) = \sum_{i=1}^p a(i)x(t-i) + u(t) \quad (1)$$

Here, the notation  $y(t)$  denotes a predicted value of time  $t$ ,  $x(t)$  does a measured value,  $a(i)$  does AR parameter,  $u(t)$  does white noise, and  $p$  does the order. AR parameter,  $a(i)$ , is calculated by using Yule-Walker equation defined by (2).

$$\begin{pmatrix} R(0) & R(1) & \cdots & R(p-1) \\ R(1) & R(0) & \cdots & R(p-2) \\ \vdots & \vdots & \ddots & \vdots \\ R(p-1) & R(p-2) & \cdots & R(0) \end{pmatrix} \begin{pmatrix} a(1) \\ a(2) \\ \vdots \\ a(p) \end{pmatrix} = \begin{pmatrix} R(1) \\ R(2) \\ \vdots \\ R(p) \end{pmatrix} \quad (2)$$

Here, the notation  $R(i)$  denotes auto covariance function. Moreover, the order,  $p$ , is determined on the basis of Akaike's Information Criterion (AIC) [9], [10]. In our experiment, the order,  $p$ , is determined from the time-series data of 365 days. That is, we vary  $p$  from 1 to 365, and then calculate the value of AIC by (3).

$$AIC = -2\ln(L) + 2k \quad (3)$$

Table I  
Subjects Data

| Subject | Sex  | Age | Range of body weight change (kg) | Height (cm) |
|---------|------|-----|----------------------------------|-------------|
| A       | Male | 35  | 66.6 ~ 71.1                      | 180.0       |
| B       | Male | 35  | 68.7 ~ 79.4                      | 173.0       |
| C       | Male | 39  | 74.8 ~ 88.3                      | 176.0       |
| D       | Male | 36  | 60.6 ~ 65.2                      | 157.0       |
| E       | Male | 41  | 95.6 ~ 105.0                     | 175.0       |
| F       | Male | 36  | 65.3 ~ 69.1                      | 174.5       |

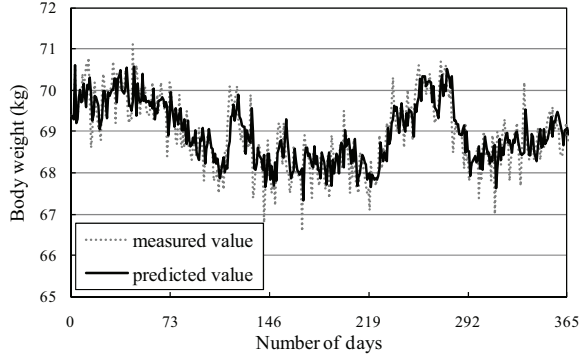


Figure. 1 Prediction result in subject A

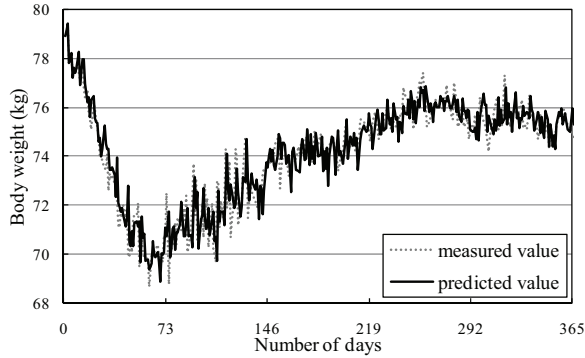


Figure. 2 Prediction result in subject B

Here,  $L$  denotes maximum likelihood and  $k$  does number of free parameter. Maximum likelihood,  $L$ , is changed by  $p$ . The order of AR model is determined as  $p$  with the minimum  $AIC$  during  $[1, 365]$ . We predict body weight of next day from time-series data of last  $p$  days.

### III. PREDICTION RESULTS OF ONE DAY

In our experiment, we employed body weight data while 365 days of 6 subjects in Table I. We predicted their body weight change by AR model. We evaluated our prediction results by using correlation coefficient between predicted values and truth values. We tested AR model 5 times and calculated the mean and the standard deviation (SD).

Fig. 1 shows prediction result of subject A. Subject A has rapid body weight change during  $[109, 117]$ . From Fig. 1, we can see that AR model predicted this rapid change. Fig. 2 shows prediction result of subject B. Subject B has body weight change of about 10 kg during about 2 months. From Fig. 2, we can see that AR model predicted this change. Fig. 3 shows the prediction result of subject C. Subject C has slowly decreasing body weight data. In Fig. 3, AR model predicted this slow change. Fig. 4 shows the prediction result of subject D. Subject D has decreasing body weight data in short term. From

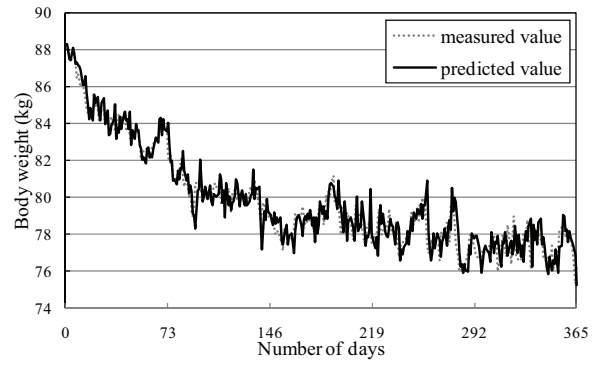


Figure. 3 Prediction result in subject C

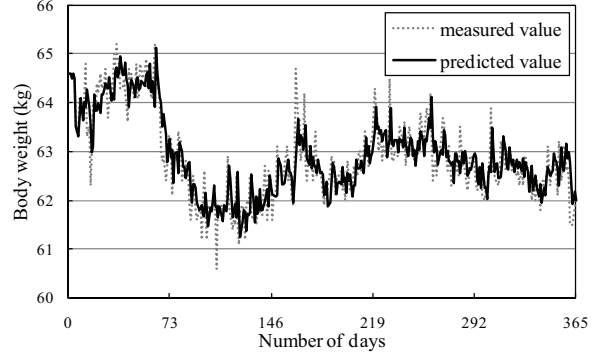


Figure. 4 Prediction result in subject D

Fig. 4, we can see that AR model predicted this change in short term. Fig. 5 shows the prediction result of subject E. Subject E has rapidly body weight change during about 10 days. From Fig. 5, we can see that AR model predicted this change during about 10 days. Fig. 6 shows prediction result of subject F. Subject F has rapid body weight change during a few days. From Fig. 6, AR model then did not predict this rapid change during a few days.

Table II shows the mean  $\pm$  SD of correlation coefficient and the determined order of AR model. We obtained  $0.798 \pm 0.073$  in the average.

### IV. PREDICTION METHOD BY FUZZY-AR MODEL

The orders of AR model are different from person to person. The order would represent a cycle of body weight of individuals. By calculating the order,  $p$ , we will predict body weight change of next  $p$  days.

To find the weight cycle, we employ 100 subjects and determine the order for each subject. All subjects are ranged from 24 to 79 years old (male: 87 and female: 13). Fig. 7 shows histogram of the orders. In Fig. 7, the peak frequency is 3 or 7 and their neighbors. Also, 14 is larger than its neighbors. From these results, we consider that the frequency is 7 days as the highest peak and 3 days as the second. Especially some persons have 14 days. We propose a Fuzzy-AR model with a fuzzy membership function. The fuzzy membership function defined from the order,  $p$ , where the order is individually determined as the highest frequency of the AR model. The notation  $t_x$  denotes the current point. Fuzzy-AR model is defined by (4).

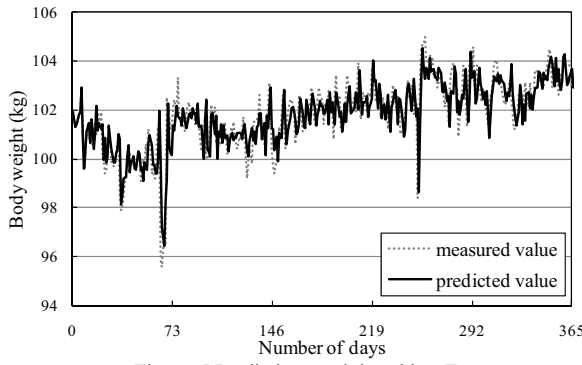


Figure 5 Prediction result in subject E

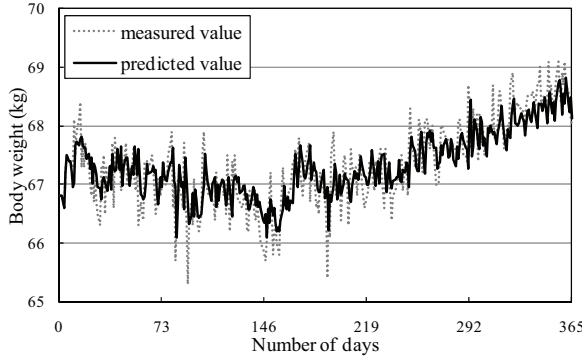


Figure 6 Prediction result in subject F

Table II  
Prediction Results

| Subject | Order of AR model $p$ | Correlation coefficient |
|---------|-----------------------|-------------------------|
| A       | 8                     | $0.734 \pm 0.014$       |
| B       | 9                     | $0.872 \pm 0.015$       |
| C       | 3                     | $0.906 \pm 0.013$       |
| D       | 7                     | $0.807 \pm 0.013$       |
| E       | 10                    | $0.734 \pm 0.033$       |
| F       | 8                     | $0.733 \pm 0.013$       |
| Average | -                     | $0.798 \pm 0.073$       |

$$y(t_x + d) = \sum_{i=1}^p a(i)x(t_x + d - i) + u(t) + \mu_w(d) \quad (4)$$

Here,  $x(t)$  means the measured values when  $t < t_x$ , and does the predicted values when  $t \geq t_x$ . The notation  $d$  denotes a predicted day parameter during  $1 \leq d \leq p$ . The notation  $\mu_w(d)$  is fuzzy membership function defined by (5). We calculate minimal ( $W_{\min}$ ) and maximal ( $W_{\max}$ ) weights from the last  $p$  days data from  $t_x$ .

$$\mu_w(d) = \frac{x(t_x - p + d) - W_{\min}}{W_{\max} - W_{\min}} \quad (5)$$

Fig. 8 shows an example of fuzzy membership function with  $p = 3$ . Also, Fig. 9 shows an example of fuzzy membership function with  $p = 7$ .

## V. PREDICTION RESULTS OF $P$ DAYS

In this experiment, we first employed subject C and subject D in Table I. We consider 6 days body weight change data of

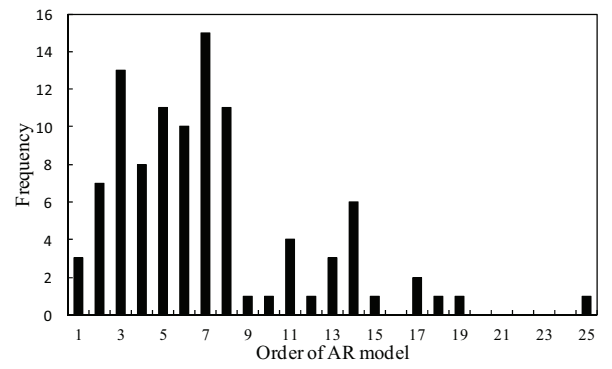


Figure 7 Histogram of order of AR model

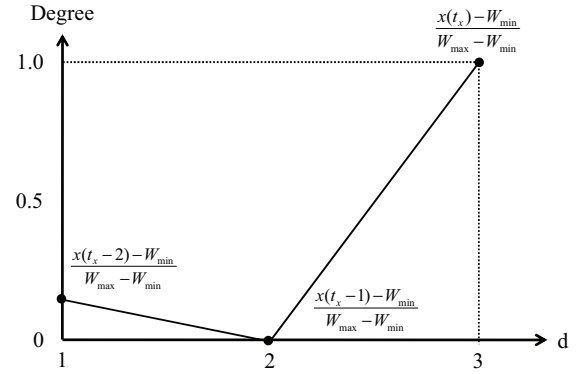


Figure 8 Example of fuzzy membership function ( $p = 3$ )

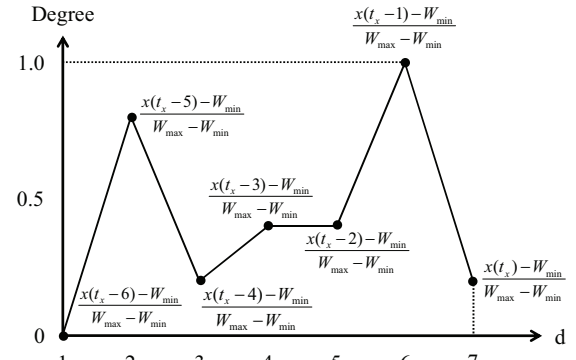


Figure 9 Example of fuzzy membership function ( $p = 7$ )

subject C because the order is 3. Fuzzy membership function was made by body weight data from 1st to 3rd days, and we predicted those from 4th to 6th days. We compare the prediction results of Fuzzy-AR model with AR model. In AR model, we use body weights from 1st to 3rd days. Furthermore, we extracted 14 days body weight change data of subject D because the order is 7. Fuzzy membership function was made by body weight data from 1st day to 7th day, and we predicted next 7 days. We compare the prediction results of Fuzzy-AR model with AR model. In AR model, we use body weight of last 7 days. We evaluated these prediction results by correlation coefficient between predicted values and truth values. We tested these models 100 times and calculated the mean and SD.

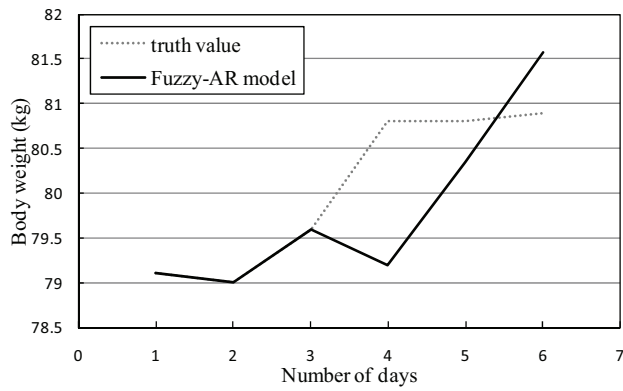


Figure. 9 Prediction result using Fuzzy-AR model in subject C

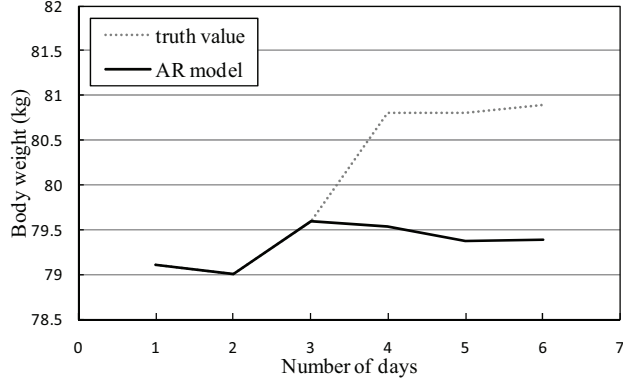


Figure. 10 Prediction result without using AR model in subject C

Fig. 9 shows prediction result using Fuzzy-AR model in subject C. The correlation coefficient was  $0.571 \pm 0.413$ . Fig. 10 shows prediction result using AR model in subject C. The correlation coefficient was  $0.232 \pm 0.615$ . Fig. 10 shows prediction result using Fuzzy-AR model in subject D. The correlation coefficient was  $0.542 \pm 0.187$ . Fig. 11 shows prediction result using AR model in subject D. The correlation coefficient was  $0.176 \pm 0.341$ . Thus, the accuracy using Fuzzy-AR model is higher than that using AR model.

## VI. CONCLUSIONS

In our study, we predicted body weight change based on AR model. We predicted body weight change of 6 subjects by AR model. We tested AR model 5 times and calculated the mean of correlation coefficient. As a result, the AR model obtained  $0.798 \pm 0.073$  in correlation coefficient between predicted and measured values. Next, we determined body weight change cycle from 100 persons data. Then, the peak frequency is 7 days. Next, we propose a Fuzzy-AR model for body weight data from last  $p$  days, where  $p$  is the order of AR model, and we predicted next  $p$  days. As a result of 2 subjects, Fuzzy-AR model obtained  $0.558 \pm 0.317$  in correlation coefficient. This value was higher than AR model ( $0.204 \pm 0.497$ ). Thus, Fuzzy-AR model accurately predicted body weight change of next 3 or 7 days than AR model.

In the future, we will improve prediction accuracy by considering the other attributes such as calories and athletics.

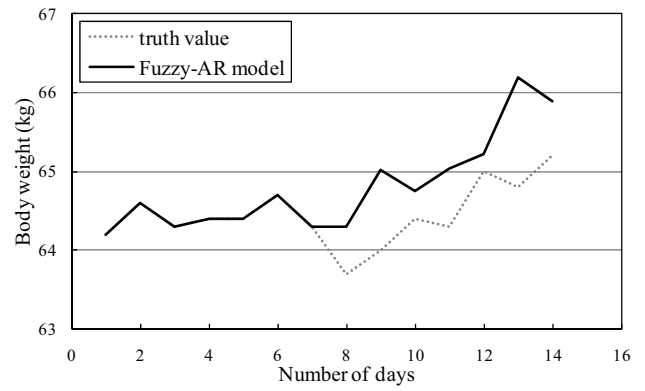


Figure. 11 Prediction result using Fuzzy-AR model in subject D

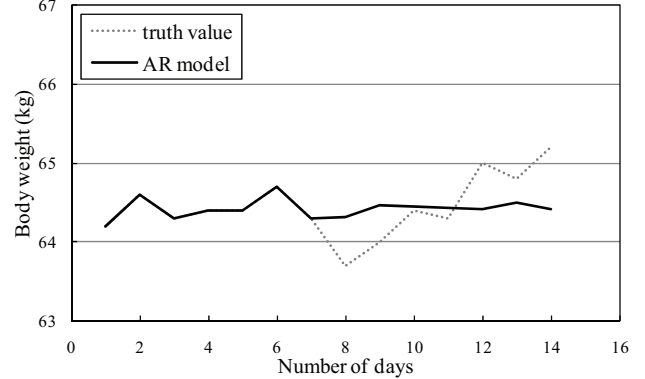


Figure. 12 Prediction result without using AR model in subject D

## REFERENCES

- [1] Continua Health Alliance home page, <http://www.continuaalliance.org/index.html>
- [2] J. Wang and T. Zhang, "Degradation prediction method by use of autoregressive algorithm," IEEE ICIT, pp. 1-6, April 2008.
- [3] F. M. Bennett, D. J. Christini, H. Ahmed, K. Lutchien, J. M. Hausdorff, N. Oriol, "Time series modeling of heart rate dynamics," Computers in Cardiology, p.273, September 1993.
- [4] W. Gersch and T. Brotherton, "AR model prediction of time series with trends and seasonalities: A contrast with Box-Jenkins modeling," Decision and Control including the Symposium on Adaptive Processes, vol 19, p.988, December 1980.
- [5] R. Palaniappan, P. Reveendran, S. Nishida, N. Saiwaki, "Evolutionary fuzzy ARTMAP for autoregressive model order selection and classification of EEG signals," Systems, Man, and Cybernetics, vol 5, p. 3682, October 2000.
- [6] J. Liu, J. Mo, S. Pourbabak, "Human cardiovascular system identification and application using a hybrid method of auto-regression and neuro-fuzzy inference systems," Machine Learning and Cybernetics, vol 7, p.4107, August 2004.
- [7] B. S. Chen, S. C. Peng, K. C. Wang, "Traffic Modeling, Prediction, and Congestion Control for High-Speed Networks: A Fuzzy AR Approach," IEEE Transaction on Fuzzy Systems, vol 8, pp. 491-508, October 2000.
- [8] N. Watanabe, "A Fuzzy Rule Based Time Series Model," Fuzzy Information, vol 2, p.936, June 2004.
- [9] H. Akaike, "A new look at the statistical model identification," IEEE Transactions, vol 19, pp. 716-723, December 1974.
- [10] R. Shibata, "Selection of the order of an autoregressive model by Akaike's information criterion," Biometrika, vol 63, pp. 117-126, June 1975.