Assessment of Arteriovenous Shunt Pathway Function and Hypervolemia for Hemodialysis Patients by Using Integrated Rapid Screening System

Wei-Ling Chen[1], Chia-Hung Lin[1], Chung-Dann Kan[2,*]

[1]Department of Engineering and Maintenance, Kaohsiung Veterans General Hospital, Kaohsiung, Taiwan.

[2]Division of Cardiovascular Surgery, Department of Surgery, National Cheng Kung University Hospital, College of Medicine, National Cheng Kung University, Tainan, Taiwan.

Received 06 January 2016; received in revised form 25 March 2016; accepted 01 April 2016

Abstract

Currently, the hemodialysis patients received body weight measurement by themselves, vital sign checking by nursing staffs before dialysis. Whenever, the arteriovenous routes with problems doubted, the patients needed to be referred to surgeon for vascular echography checking and then to be corrected. How to integrate these three tasks in one time is a very important issue. The project proposes to combine our previous study of audio-phono angiographic technology in detecting vascular stenosis with rapid screening system to evaluate dialysis patients' arteriovenous routes function and their status of excess body fluids: inspecting and integrating the blood pressure, body weight, and fistula function work into a rapid screening system, and using the quantization of fistula phono angiography pitch to achieve assessing arteriovenous routes. Future hoping is developed a complete integrated intelligence system by combining the arteriovenous fistula signal processing with feature extraction with wireless sensor network technology.

Keywords: arteriovenous shunt, screening system, hypervolemia, dual-core embedded system

1. Introduction

Chronic kidney disease is a global public health problem with high morbidity and mortality. Treatment of end-stage renal disease (ESRD) typically involves a kidney transplant or dialysis, which assists damaged kidneys in removing waste and excess fluid from the body. In Taiwan, the incidence and prevalent rates of ESRD were the highest in the world [1], hemodialysis is the most common choice for ESRD patients. However, to perform a hemodialysis, surgeons must create pathological fistulas to provide vascular access routes for treating ESRD. Arteriovenous access (AVA) stenosis is regarded as the primary cause of AVA dysfunction in hemodialysis patients and a common occurrence in patients undergoing extended hemodialysis therapy. According to NKF-DOQI guidelines [2], regular monitoring and surveillance of AVA function is mandatory. Basically, AVA is a continuous circuit that starts and ends at the heart; it is not simply an anastomosis. Moreover, clinical assessments are based on a physical examination of AVA. Three physical examination steps are look, feel, and listen. Clinically, AVA flow rates must reach 600–1000 mL/min for hemodialysis treatment to be considered efficient. This high-flow volume causes vibration of the vascular wall, which then transmitted to the skin surface, manifesting as a palpable thrill or audible bruit [3]. The state of body water is an important factor in the routine hemodialysis (HD) treatment and post-dialysis healthcare. Hypervolemia is a medical condition as excess body water in the blood, leading to increases in body sodium (Na) content and a consequent increase in extra-cellular body water. When dialysis patients suffer from hypertension will increase in weight and peripheral edema in the legs and arms [4-6].

The purpose of this paper is to combine our previous study of audio-phonoangiographic technology in detecting vascular stenosis with rapid screening system to evaluate dialysis

* Corresponding author, Email: kcd56@mail.ncku.edu.tw

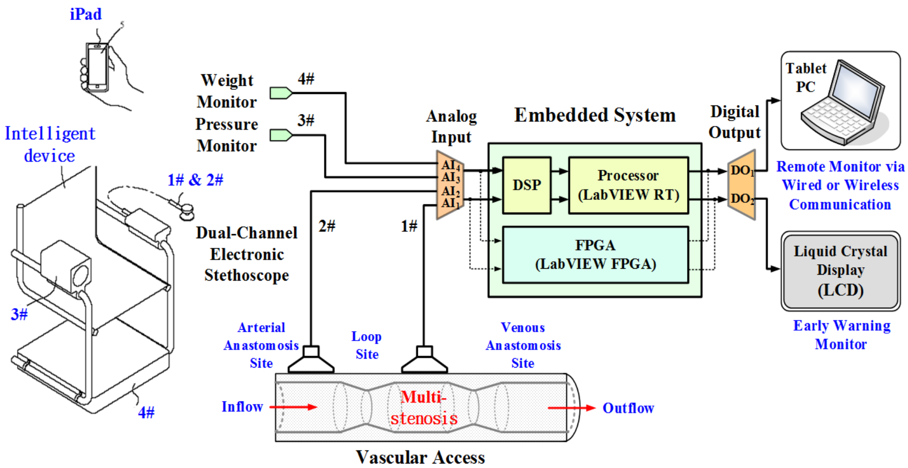


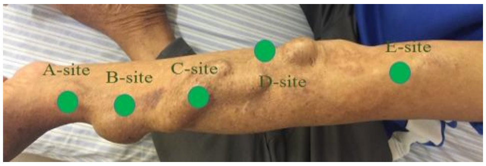
Fig. 1 Block diagram of the rapid screening system

patients' arteriovenous routes function and their status of excess body fluids: inspecting and integrating the blood pressure, body weight, and fistula function work into a rapid screening system, and using the quantization of fistula phonoangiography pitch to achieve assessing arteriovenous routes. The feasibility of the integrated rapid screening system will be provide an easy operational instrument for efficacious and real time monitoring arteriovenous routes (Fig.1). First, the screening system employed National Instruments (NI) myRIO dual-core embedded microprocessor system integrated with system sensors, software, wireless/wired communications, and output display unit in developing a system which is suitable for rapid screening on hemodialysis units. Second, the screening system is to use audio signal feature extraction algorithms, fuzzy algorithms, and excess body fluid assessment methods on starting begin human status checking. Using vascular echography results as of the narrow criterion to establish the judgment database, and create an alert threshold as indicators of future development, therefore, to achieve the best diagnostic work. Future hoping is developed a complete integrated intelligence system by combining the arteriovenous fistula signal processing with feature extraction with wireless sensor network technology.

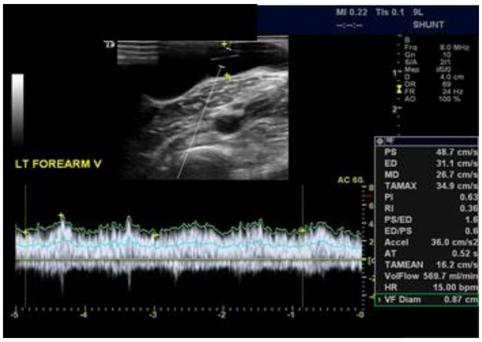
2. Method

2.1. Preliminary Diagnosis and Classification

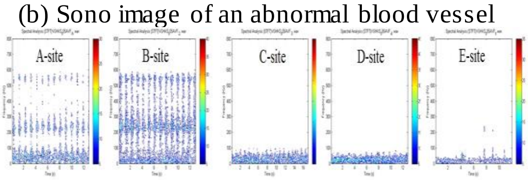
In clinical research, the degree of narrowing of normal vessels has been used as an index for the degree of AVA in patients. Examination results have been used as a reference to confirm the DOS according to X-ray or sono images. For the measurement segment A site-E site (Fig. 2), the DOS is defined as follows [7-9].



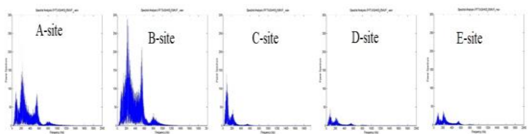
(a) The detection site



(b) Sono image of an abnormal blood vessel



(c) Spectrum of Short-time Fourier transform



(d) Spectrum of Fourier transform

Fig. 2 Sono angiography and spectrum analysis in clinical reasearch

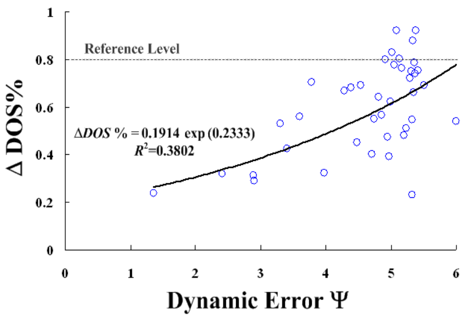
$$DOS\% = (1 - \frac{d^2}{D^2}) \times 100\% \quad (1)$$

$$\Delta DOS\% = (DOS_{pre}\% - DOS_{post}\%) \quad (2)$$

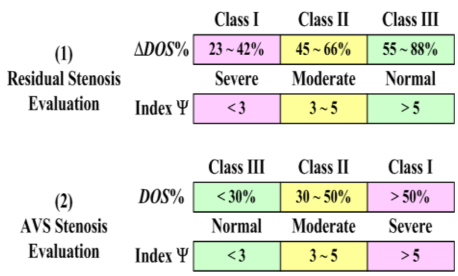
2.2. Design of fuzzy Petri nets (FPNs)Screening System Based on Fractional-Order Dynamic Error

Regarding the surgical outcomes of the 42 patients, the overall pre-PTA DOS% was above 80%, which was regarded as the reference level, whereas the post-PTA DOS% was distributed across three groups (i.e., > 50%, 30%–50%,<30%). No statistical significance was observed between the groups at the A sites and V sites ($p > 0.05$). Therefore, the correlation between ΔDOS% and index Ψ is stronger at the V sites than at the A sites [7]. Exponent regression was used to model the relationship between ΔDOS% and index Ψ and between DOS% and index Ψ. The prediction model fit a nonlinear curve passing directly through all of the experimental data, as shown in Fig. 3(a). The correlation between ΔDOS and index Ψ at the V site can be expressed as:

$$\Delta DOS\% = 0.1914 \times \exp(0.2333\,\Psi),\quad R^2 = 0.3802 \quad (3)$$



(a) ΔDOS % versus index Ψ at the V site



(b) evaluation of the severity of AVA stenosis

Fig. 3 Evaluation of the severity of AVA stenosis at the V site with DOS % versus index

Exponential regression was used to perform a least squares curve fit, which minimized the sum of the squares of the deviations of the experimental data values extracted from the prediction model, thereby obtaining the examination criteria for the prediction. Fig. 3(b) depicts the range of pre-PTA DOS residuals (Class I: Ψ < 3, Class II: 3 < Ψ < 5, and Class III: Ψ > 5), which were used as a baseline for evaluating the post-PTA DOS residuals. We also compared the pre- and post-PTA Ψ indices monthly and determined the ideal ranges for evaluating the severity of AVA stenosis in the order of Class III (Ψ < 3), Class II (3 < Ψ < 5), and (Class I: Ψ > 5).

(1) A Gaussian membership function can be parameterized by mean (mean = 0–6) and standard deviation ($\sigma1 = \sigma2 = \sigma3 = \ldots = \sigma r = 0.3802$) by applying Equation (4).

$$\mu_r = \exp[-\frac{(\psi_r - mean)^2}{\sigma_r^2}] \quad (4)$$

(2) Fig. 4 depicts the Gaussian membership functions for the three classes. Through this approach, we obtained seven membership functions μr, $r = 1, 2, 3, \ldots, 7$, with specific ranges denoted as Ψ_r. The CF of each input in the various ranges is within the range of [0,1]. The FPN can perform fuzzy inference calculations to evaluate the DOS for each proposition specified by a clinical physician. Assume that for the degree of proposition C_m (Classes I–III), $m = 1, 2, 3$, and place p_m is associated with the proposition $d_m = \theta_m(p_m)$, $m = 1, 2, 3$..

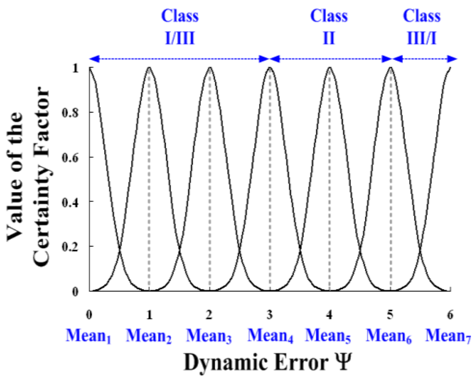
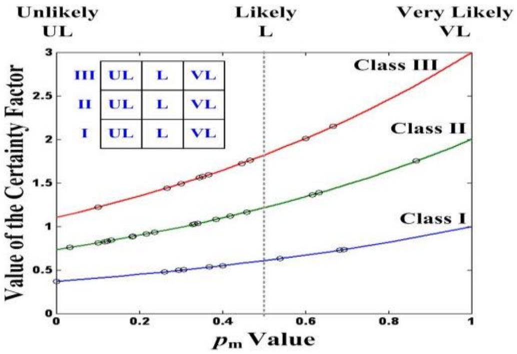


Fig. 4 Gaussian membership functions for the three classes of DOS

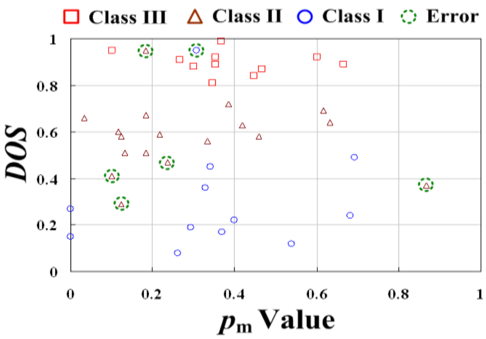
3. Results and Discussion

3.1 Feasibility Tests with the Proposed Screening System

Fig. 5(a) and (b) show the overall test results; compared with the *DOS*% results, the accuracy is 85.71% with six failures. The measurement sites, quantification errors, and undetected stenosis could affect the efficiency of the proposed method. The study used at least two 8-second records from the measurement site of 21 patients (i.e., pre- and post-PA). We determined three DOS classes. The terms UL, L, and VL correspond to monotonically decreasing curves that define the degree of certainty. The output of function θ_m may be an arbitrary curve that can be defined as a function that must vary between 0.3679 and 3.000. The place p_m can determine the DOS level, and more likely closes to value 1, 2, or 3 for the goal proposition. If place p_m is only partially similar, its value is less than 1 and it gradually decays to 0. From these results, we determined the function of AVS, which can be evaluated using the proposed diagnosis system.



(a) Feasibility diagnosis results for the 42 tests



(b) degree of stenosis (DOS) versus pm

Fig. 5 Feasibility diagnosis results for the 42 tests, and the degree of stenosis (DOS) versus pm

Due to variations in the frequency spectra of the various classes and differences among the patients, the characteristic frequencies occupy a range of frequency bands, with some characteristic frequencies overlapping or crossing bands. Physicians determined the final degree of certainty as a function of the variance in frequency and magnitude. However, obtaining the diagnosis results required an off-line analysis. Traditional Petri nets (PNs) require constant transitions and weighted parameters (β and W), and they encounter difficulty in handling variance in the frequency spectra. PNs were considered appropriate for processing binary data in true–false decisions, on–off switching, and automatic control applications [10]. Comparing FPNs with PNs, the inference rules in the knowledge base of the rule-based system are both modeled. FPNs use the CF of the fuzzy inference rules and weights of the propositions by using binary data and can automatically perform weighted fuzzy reasoning calculations for analyzing spectral variance. Thus, the proposed rule-based diagnosis system can perform fuzzy inference calculations in a flexible and intelligent manner.

3.2. Long-Term Examination Using Frequency Parameter-Based Fuzzy Petri Net

A 54-year-old female patient undergoing hemodialysis treatment with an AVG (right forearm loop) agreed to participate in a long-term examination. Data were collected between June 25, 2011, and July 11, 2012. In a routine monitoring cycle, monthly examinations were performed to evaluate AVG function. Over 3 months of observation, the first characteristic frequency gradually increased from 68 to 170 Hz (Fig. 6). On September 6, 2011, the patient presented with a severe AVG occlusion, and a physician confirmed Class II stenosis. Ultrasonic examination indicated a DOS% of 66% at the measurement site, and the patient received PTA treatment. The three characteristic frequencies were 170, 425, and 681 Hz.

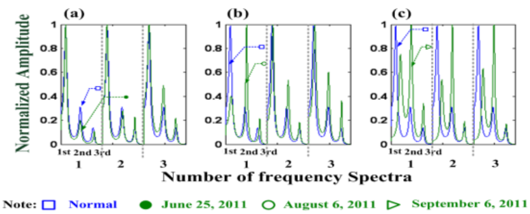


Fig. 6 Long-term examination at V site from June 25, 2011, to September 6, 2011

4. Conclusion

In an embedded system development environment, we used four fundamental arithmetic and logical-reasoning operations to configure the combinational logics or ASICs, and then embedded the intelligent algorithms into a compact chip. The proposed diagnosis system allows rule-based configuration and automatic weighted fuzzy reasoning calculations. Flexible and intelligent algorithms require no iteration for updating system weights. Therefore, this system can handle complex configuration designs and is appropriate for the short design cycle of prototype implementation, testing, debugging, and modification. Currently, graphical user interfaces of Windows-based applications enable reprogramming and have flexible architectures that facilitate the rapid development of customized ASICs. The proposed FPN algorithm can be implemented using four fundamental operations with specific data structures. Therefore, it can also be implemented with the four fundamental operations. By combining an FPN and logical operation functions, the proposed diagnosis system provides a promising means for implementing a portable monitor for AVS evaluation in home care.

Acknowledgement

This study is supported in part by the research grant of Kaohsiung Veterans General Hospital (VGHKS105-070) and the Ministry of Science and Technology, Taiwan (MOST), under contract number: MOST105-2218-E-075B -001.

References

[1] A. J. Collins et al., "USRDS 2012 annual data report: atlas of chronic kidney disease and end-stage renal disease in the United States," American J. Kindeny Diseases, vol. 59, pp. 342, 2012.

[2] N. K. Foundation, "KDOQI clinical practice guidelines and clinical practice recommendations for 2006 updates: hemodialysis adequacy, peritoneal dialysis adequacy and vascular access," Am. J. Kidney Dis., vol. 48, pp. 1-322, 2006.

[3] F. Loth, P. F. Fischer, and H. S. Bassiouny, "Blood flow in end-to-side anastomoses," Annu. Rev. Fluid Mech., vol. 40, pp. 367-393, 2008.

[4] P. W. Chamney, K. Matthias, C. Rode, W. Kleinekofort, and V. Wizemann, "A new technique for establishing dry weight in hemodialysis patients via whole body bioimpedance," Kidney International, vol. 61, pp. 2250-2258, 2002.

[5] A. H. Tzamaloukas, G. H. Murata, D. J. Vanderjagt, K. S. Servilla, and R. H. Glew, "Body composition evaluation in peritoneal dialysis patients using anthropometric formulas estimating body water," Advances in Peritoneal Dialysis, vol. 19, pp. 212-216, 2003.

[6] R. Agarwal, "Hypervolemia is associated with increased mortality among hemodialysis patients," Hypertension, vol. 56, pp. 512-517, 2010.

[7] Y. C. Du, W. L. Chen, C. H. Lin, C. D. Kan, and M. J. Wu, "Residual stenosis estimation of arteriovenous grafts using a dual channel honoangiography with fractional-order features," IEEE Journal of Biomedical and Health Informatics, vol. 18, no. 2, pp. 703-713, 2014.

[8] W. L. Chen, C. H. Lin, T. Chen, P. J. Chen, and C. D. Kan, "Phono angiography with a fractional order chaotic system - A new and easy algorithm in analyzing residual arteriovenous," Medical & Biological Eng & Computing, vol. 51, pp. 1011-1019, 2013.

[9] W. L. Chen, C. H. Lin, T. Chen, P. J. Chen, and C. D. Kan, "Stenosis detection using burg method with autoregressive model for hemodialysis patients," Journal of Medical and Biomedical Engineering, vol. 33, no. 4, pp. 356-362, 2013.

[10] R. S. Lees and C. F. Dewey, "Phono angiography: a new noninvasive diagnostic method for studying arterial disease," Proceedings of the National Academy of Sciences, vol. 67, no. 2, pp. 935-942, 1970.