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An Adaptive fuzzy based Evaluation of Fetal Congenital Heart Defects

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ABSTRACT: Fetal Monitoring during pregnancy is crucial to adult health in later life. In particular, the monitoring of the fetal cardiovascular system is of a great importance; because cardiac system responds to any fetal compromise in utero The variation in the distribution of the maternal-fetal synchronization ration between the early and late normal groups might indicate a healthy development of the autonomic nervous system while the higher variation in the phase coherence (locking) index in the CHD group could be a good marker for impairment of cardiac autonomic activity.Further coupling analysis with more abnormal cases is needed verify these findings. Also, a limitation of exsiting is that the collected data was of 1-min length which is too short to control the fetal states. However, short term recording is typically used for clinical investigation in pregnancy clinic. Longer signal durations (5–10 min) used to verify these findings in proposed fuzzy based approach

I. INTRODUCTION

The human body is functioning properly due to the co-ordinated action of various systems such as skeletal system, Circulatory system, Respiratory system, Digestive system, excretory
System, Regulatory System, Reproductive System and Muscular System. A number of organs in the body that function in a co-ordinated manner form a system. For example, the heart, arteries, capillaries and veins constitute the circulatory system.

II. ANATOMY AND WORKING OF THE HEART

The circulatory system is a type of transport system. The circulatory system, helps in supplying oxygen and digested food to different parts of our body and removing carbondioxide from the blood. The heart is the centre of the circulatory system. The heart is made up of muscles. It acts as a pump. The heart pumps blood by a movement called heart beating. The heart pumps the blood through the pulmonary circulation to the lungs and through the systematic circulation to other organs of the body.
Figure 1.1 shows how the blood is circulated in the heart through block diagram. In the pulmonary circulation, the venous blood flows from the right ventricle of the heart through the pulmonary artery to the lungs where it is oxygenated and gives off carbon dioxide.

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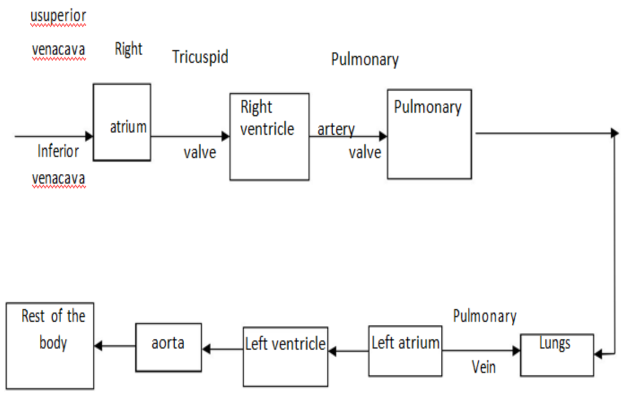

Figure 1.1 Block diagram of blood circulation in the heart

III. FETAL ELECTROCARDIOGRAM

Fetal Heart Development

The heart is among the first organs developed in the fetus and undergoes a considerable amount of growth in the very early stages of pregnancy. The most critical period of the development of fetus and its heart is between 3 and 7 weeks after fertilization, when a simple heart tube assumes the shape of a four chambered heart. The heart is believed to begin beating by the 3rd week of life and pumps its own blood through a separate closed circulatory system with its own blood type. Shortly after, the eye, ear and respiratory systems begin to form. The fetal heart can then be externally monitored by ultrasound imaging in the 7th to 9th week; although only vague images are recordable at this step. The cardiac waveforms and beat-to-beat variability of the heart rate are not measurable in ultrasound imaging. At 20 weeks, the fetal heart beat can be heard without amplification, with a rate of around 120-160 beats per minute, but little extra diagnostic information can be ascertained from auscultation above heart rate.

At 6 weeks post fertilization, brain waves can be recorded, the skeleton is complete and most reflexes are present. However, the embryo is only about 0.5cm in length and the head, mouth, liver, and intestines are just beginning to take shape. At 12-14 weeks (when the fetus weighs around 30g and is about 7cm long), the muscles begin to develop and spontaneous movements can be observed which intensify with age. Rather late into the pregnancy, at around 26 weeks, the fetus begins to inhale and exhale. Of course, the fetus is not breathing air and oxygenating the blood through this action. This is thought to aid with the production of surfactant and exercise the respiratory system before birth. Although the fetus is capable of living outside the womb at 23-24 weeks, this would be considered premature at birth, and the normal gestation time is approximately 40 weeks. In fact, at 23 weeks there is only a 15% chance of viability outside of womb with the viability probability rising to 56% at 24 weeks and 79% at 25 weeks

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Table 1.2 Comparison between Adult and Fetal ECG

Feature	Adult ECG (sec)	Fetal ECG (sec)
P wave	0.06-0.1	0.065
T wave	0.16	0.139
P-Q segment	0.12-0.2	0.104
Q-T segment	0.35-0.42	0.25
R-R segment	0.75 -1	-
S-T segment	0.02-0.12	0.057
QRS complex	0.06-0.1	0.65

III. EXISTING APPROACH

Fetal Monitoring during pregnancy is crucial to adult health in later life. In particular, the monitoring of the fetal cardiovascular system is of a great importance; because cardiac system responds to any fetal compromise in uterus. The fetal cardiovascular system is highly dependent on oxygenized blood that is supplied through the umbilical cord and placenta exchanging with the maternal blood and bypassing the respiratory system. As such there has been a growing interest to look at relationship between the maternal and fetal cardiac function so that better understanding of how maternal factors affect fetal development. Previous studies have shown variations in fetal heart rate variability (FHRV) due to physiological and psychological states of the mother. Situations such as maternal stress and anxiety, exercise and low level of blood oxygen resulted in FHR changes [1-4]. Different signal processing methods have been used to study this proposed coupling between the mother and the fetus that include: phase synchronization, transfer entropy, partial directed coupling and joint symbolic dynamics [5-8]. Synchronization (or entrainment) has been demonstrated between different physiological systems such as the cardio respiratory and the cardio-locomotion interaction [9, 10]. The intermittent episodes of phase locking behavior of fetal and maternal heart rates were observed by a number of researchers in the past [11-13]. Using phase synchronization, Van Leuven et al. have shown beat by beat synchronization between mother and fetus heartbeats [7]. Ivanovo et al. have found that the maternal-fetal heart rate coupling is independent to maternal respiratory system [13]. Wang et al. have shown significant differences in synchronization epochs between 3 gestational age groups The specific mechanism leading to maternal–fetal heart rate coupling remains unexplained and previous studies proposed two hypotheses for pathways mediating this interaction: (i) the oscillatory rhythm of maternal respiration acts as a common driving force and influences simultaneously both maternal and fetal heart rates, leading to an apparent maternal–fetal heartbeat synchronization; (ii) the maternal cardiac system has a direct acoustic stimulus effect on the fetal heart rhythm. Further investigations are needed to clarify the physiological significance of the maternal–fetal heart rate coupling, and whether fetus can benefit from this specific interaction. Therefore, the aim of the present study is to illustrate the fetal- maternal heart rate synchronization by combining all possible patterns of phase locking events over the gestational progress and to check how the combined patterns turn different in case of fetuses with congenital heart anomalies**.** In this work, we extend the maternal-fetal synchronization analysis by introducing two features: (1) the probability distribution of the synchronization ratio and (2) the phase coherence index between maternal and fetal heart beats. We apply these features to study maternal-fetal heart rate synchronization in early and late gestation fetuses and evaluate variations in the synchronization due to congenital heart defect (CHD). One-minute maternal ECG (mECG) and abdominal ECG records were collected from 44 pregnant women at Tohoku University Hospital. Among those: 22 had normal

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pregnancies with gestational age < 32 weeks (early group), 15 normal pregnancies with gestational age > 32 weeks (late group) and 7 pregnancies with fetuses having different types of congenital heart defects (CHD) 5 of them with gestational age < 32 weeks. Fetal ECG (fECG) traces were extracted using a method that combines cancellation of the mother's ECG signal and the blind source separation with reference (BSSR) [15]. Also, 26 other maternal and fetal heart rates were extracted from maternal and fetal phonocardiography data as described in [16]. All of the phonocardiography cases were from late gestation pregnancies. Two features were computed, these were the probability distribution of the synchronization ratio [14] and the phase coherence index

1) Synchronization is defined as the consistent number of fECG R waves (n) within the primary mECG cycles (m) which could have multiple numbers of cycles. The synchronization ratio can then be represented as m:n. In this work we used m=1:4 cycles. The probability distribution of the n fECG R-waves for each m cycles is computed

2) The phase coherence index (λ) determines the coherence spectral estimator for bivariate time series. The value of λ ranges from 0 to 1, where λ = 1 denotes complete synchronization. The phase coherence index is computed as:

$$\lambda(k) = \left|\frac{1}{N}\sum_{n=k-N}^{k} e^{j\psi(n)}\right|$$

Where ψ(n) is the relative phase of the fetal R peak within the maternal primary heart cycle

$$\psi(n) = \frac{\phi(n)\, mod(2\pi)}{2\pi}$$

And ϕ(n) is the instantaneous phase of the fetal nth R peak computed as:

$$\phi(n) = \frac{2\pi(m_n - m_k)}{(m_{k+1} - m_k)}$$

Where mk and mk+1 are the time instants of the maternal R peaks between which the nth fetal R peak occurs and mn is the time instant of the nth fetal R peak. In this work, we computed λ for segments of window size (N) of 10 fECG R peaks and the mean (λ_mean) and standard deviation (λ_SD) of these segments were computed. Kruskal-Wallis test was used to compare significant differences between the Early, Late and CHD groups.

IV. PROPOSED APPRAOCH

The analysis of electrocardiograms (ECGs) helps physicians make their cardiac diagnosis. Therefore a large store of medical knowledge and practical experience is required. In this paper we report on our investigations of a rule-based fuzzy logic system that processes ECG data using the knowledge of a medical expert. The aim is to give support to the physician for his diagnosis. In this first consideration we discuss single modules of the rule-based system proposed and moreover we present the used input and output variables of the rule bases. The performance of the implemented rule-based fuzzy logic system is tested using ECGs with abnormalities in the P and T wave as well as in the QRS complex. The system's output corresponds to the analysis of these ECGs by a medical expert. The electrocardiography enables the registration of electric processes of the heart function. The excitation of every single cardiac muscle fiber results in the formation of different electric potentials, which sum up to the so-called integral vector. The analysis of all registered integral vectors yields information on the healthiness of the heart and thereby enables a diagnosis of different diseases of the heart rhythm and its conduction system. This interpretation of electrocardiograms (BeGs) is usually done by a physician who makes his diagnosis by additionally using other information such as the case history. Modem EeG measurement units provide an analysis of the registered time series that results in partial diagnoses, which are often erroneous due to the algorithms used and hence are unreliable. State of the art technology is based on a comparison of registered EeG data with representative reference data sets. These pattern comparison techniques have been improved for the diagnosis of several symptoms such as the ventricular tachycardia. Due to the enormous computational effort for the comparison of patterns, they will not be able to fulfill the requirements of a comprehensive diagnosis system. Rule-Based Fuzzy Logic System

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The theory of fuzzy sets and its application facilitates processing the vague knowledge of human experts in a computerized manner. Assuming that knowledge and experience of an expert - unconscious, mechanical knowledge used for classification tasks - can be acquired and collected and then translated into a computer program, it is possible to analyze electrocardiograms in an automated evaluation system Knowledge-based systems such as expert systems as well as rule-based systems such as fuzzy logic systems make explicit use of the underlying knowledge, which is thereby directly discernible and comprehensible. The implemented knowledge is structured according to its problem specification, such that it is easy to select specific knowledge representing a certain application domain. Traditional logic as used in expert systems assigns exactly one of two possible truth values - true or false, yes or no, one or zero - to every proposition. Multivalued and fuzzy logic use several or continuous values, respectively, in order to enable the semantic interpretation of propositions, expressions or formulae that are neither clearly true nor false. The implemented membership functions in the module fuzzification fuzzy system consists of four modules, namely the module for fuzzification,rule evaluation, accumulation and defuzzification

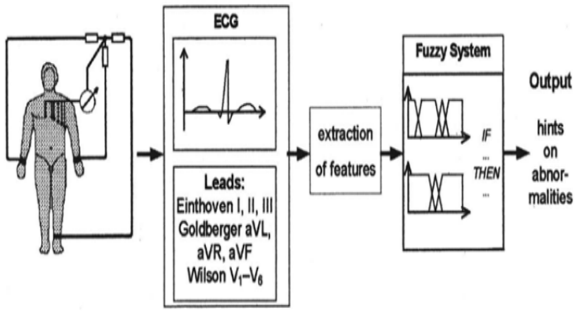

Fig. 1. Fuzzy logic system for ECG analysis

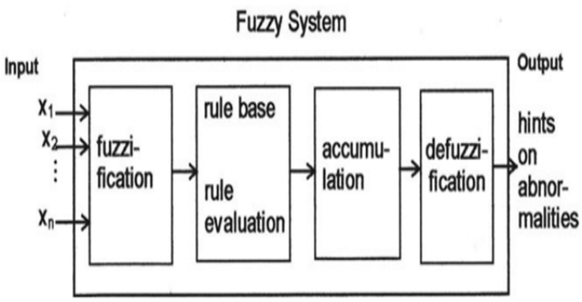

Fig. 2. Architectures of a rule-based fuzzy system

For analytical ECG diagnostics at least twelve leads are used, namely six extremity leads (I, II, III according to Einthoven and a VR, a VL, a VF according to Goldberger) as well as six thoracic wail leads VI to V6 according to Wilson. These twelve leads are generally called standard leads. The ECG signals of these standard leads are passed on to a feature extraction sub-system, where characteristic features that are used by physicians for classification and analysis are calculated. For the current system built up, the necessary features (Fig. 3.1 and 3.2) are determined manually and then passed on to the rule-based fuzzy data analysis system for further automated evaluation

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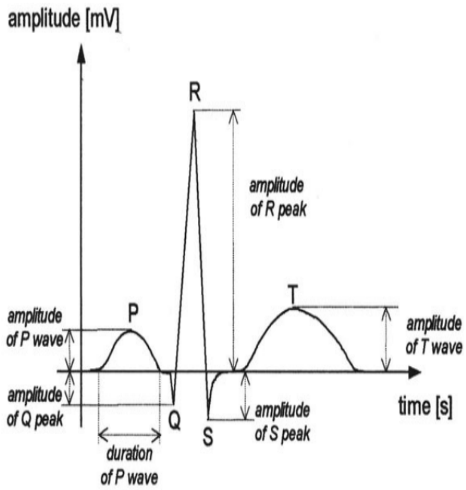

Fig. 3.1. Schematic sketch of features (here for lead II)

ECG component	definition, meaning, remarks, ...	duration limit	amplitude limit
P wave	spread of excitation in both atria	0.1 s	0.25 mV
PQ distance	atria fully excited	0.1 s	–
PQ interval	transition time, from begin of atrial ex-citation to begin of ventricular excitation	0.2 s	–
Q peak	central ventricular excitation	0.04 s	¼ R
R peak	excitation proceeds to heart tip		
S peak	end of ventricular excitation	0.06 s	
QRS complex	spread of excitation in the ventricles	0.11 s	–
ST distance	ventricles fully excited, frequency dependent		–
T wave	repolarization of ventricles		$^{1}/_{6}$ R–$^{1}/_{3}$ R
QT interval	spread of excitation and repolarization of ventricles, frequency dependent		–

Fig. 3.2. Limit values of different ECG components

Modular Structure of the Rule-Based Fuzzy Logic System

Due to the huge number of rules to be implemented we propose a modular structure of the system. Up to now, the actual system facilitates an analysis for some basic diagnoses only, but it is possible to enlarge it gradually to yield a comprehensive decision support system. The necessary knowledge was acquired from literature and was implemented in the modular evaluation system presented. The analysis system is divided into three modules, the first of which evaluates the P wave, which represents the spread of excitation in the atria, and thereby is to diagnose atrial diseases. The second module evaluates the QRS complex, which represents the spread of excitation in the ventricles. Besides the large number of diseases that may be diagnosed using the shape of the QRS complex, standard variations of its shape impede its proper analysis. Therefore and in order to build up a clear and open system that module is only to recognize low potential and R peak loss of the QRS complex for the time being. The third module that analyzes the depolarization in the ventricles, which is represented by the T wave, evaluates all twelve leads on their pathologic results. Carries out diagnostic support in selected cases, this module is only to recognize low potential and R peak loss of the QRS

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complex for the time being. The third module that analyzes the depolarization in the ventricles, which is represented by the T wave, evaluates all twelve leads on their pathologic results.

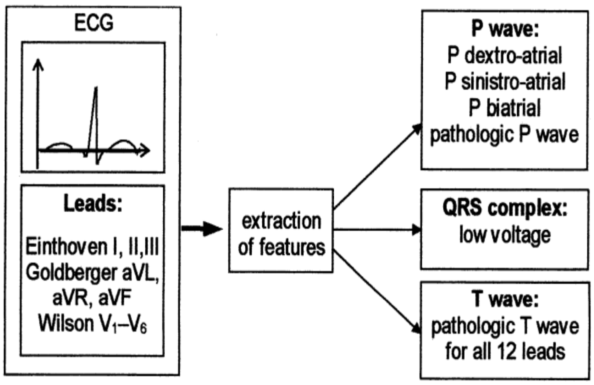

Fig. 4. Modular and expandable fuzzy logic system for diagnosis support

Module "P wave" The module fOT the evaluation of the P wave (Fig. 12.) contains rule bases that enable the decision support for the diseases P dextro-atrial (right atrium overstrained), P sinistro-atrial (left atrium overstrained) and P biatrial (both atria overstrained). In addition, the retrograde atrial excitation and the atrial flicker are joined together yielding an output value called pathologic P wave. This system uses six parameters for analysis, namely the amplitude and the duration of the P wave measured at the extremity leads II and III according to Einthoven as well as the Goldberger lead aVF. The system evaluates fOUT singular diagnoses of the diseases mentioned for each of these three leads by using fOUT rule bases (Fig.12.). This is done by fuzzifying the two parameters amplitude and duration of the P wave of every single lead and evaluating them using the appropriate rule base Linguistic. Description of the P wave For the linguistic description of the two parameters amplitude and duration of the P wave of every single lead membership functions are created (Fig. 5. and 6.) with limit values in agreement with the medical expert. Furthermore, for the output value (Fig. 7.) only three fuzzy sets are taken into account.

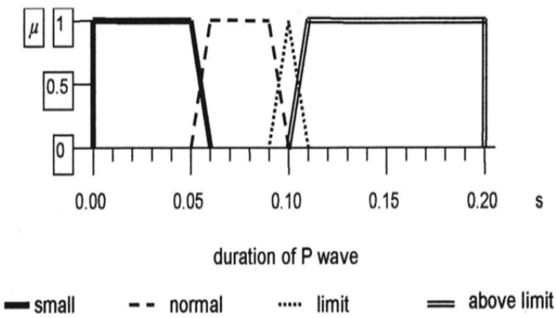

Fig. 5. Fuzzification of the duration of P wave

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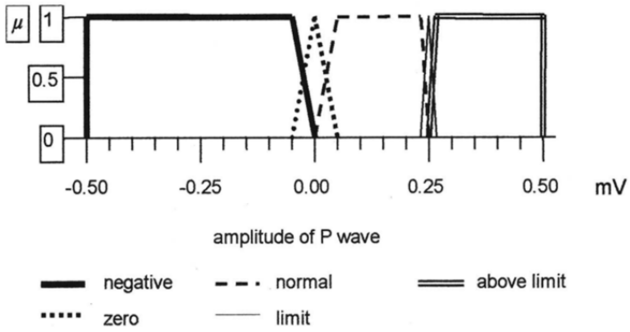


Fig. 6. Fuzzification of the amplitude of P wave

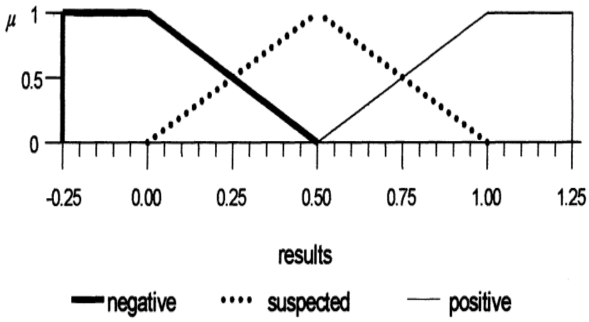


Fig. 7. Fuzzification of the output value

Usually the rule base in fuzzy systems represents a look up table of the opinion of experts or of an individual expert. In the case of the opposite opinion of e.g. two experts it is necessary to supplement the conventional architecture of a fuzzy system (Fig. 2) in such a way that the qualitative expert knowledge of the two experts can be taking into account. For the two expert rule evaluations with so called "positive" rules that express recommendations (like in conventional fuzzy systems) and "negative" rules or warning rules we need an advanced architecture of a fuzzy (Fig. 17).

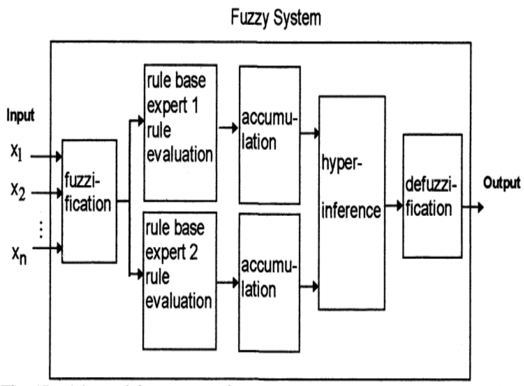
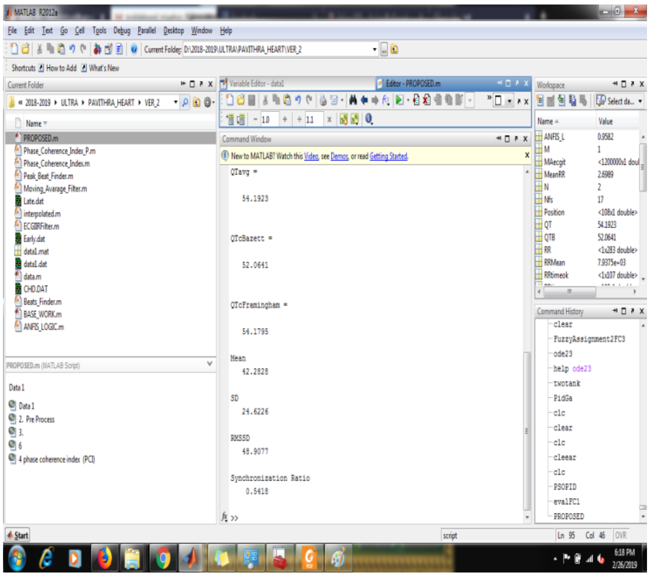


Fig. 17. Advanced fuzzy system for two expert rule evaluation rules and the negative rules with the corresponing membership functions are collected together by a hyperinference strategy which enable us to find a compromize between them

The fuzzy data analysis and medical decision support system presented was tested in off-line mode in a conventional fuzzy system. The necessary input values for the analysis system were manually extracted from the graphic ECG data sets used. The results computed by the fuzzy logic system correspond to the analysis of the ECGs of a medical expert and thereby verify the implemented rule base. In further investigations the fuzzy logic system will gradually be enlarged with modules for additional diagnoses and with an automated feature extraction module. Moreover we will investigate the reliability of the system in complex and critical situations.

V. RESULT



VI. CONCLUSION

In proposed work, we studied maternal-fetal heart rate synchronization in early and late gestation fetuses. We also evaluated variations in the synchronization due to congenital heart defect (CHD). The synchronization ratio between the mother and the fetus was more localized at certain fetus heart rate in the early gestation group while it was spreading over more fetal heart rate for the late group. The variation between the early and late normal groups might indicate a healthy development of the autonomic nervous system while the higher variation in the CHD group could be a good marker for impairment of the cardiac autonomic activity. Further coupling analysis with fuzzy model is used and verified these findings.

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