A Prototype System of Acute Stroke Type Discrimination and Monitoring Based on a Annulus Antenna Array: A Pilot Study

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Abstract. Objective: Timely and effective discrimination of hemorrhagic stroke and ischemic stroke can significantly improve the prognosis. Current discrimination is expensive and has the disadvantage of having to be in contact with the patient. Based on animal experiments, in this paper, microwave measurement technique is used to study the discrimination of two stroke types. Method: In the experiments, 10 rabbits (5 cerebral hemorrhage and 5 cerebral ischemia) are selected. Cerebral hemorrhage is induced by injecting autologous blood (1 to 4 mL) into the brain of rabbits, and the cerebral ischemia is induced by bilateral common carotid artery ligation and femoral artery blood extraction. The two groups are monitored by a 16-channel microwave detection system to obtain the reflection parameter caused by pathological changes in the brain. After redundancy removed from original data, support vector machine (SVM) is used to identify the type and severity of two types of stroke. Findings: The study shows that the microwave-based stroke identification system can effectively distinguish the cerebral hemorrhage model and the cerebral ischemia model. The experimental system is very promising in pre-hospital stroke type identification because of low cost, non-invasive, simple operation and rapid measurement.

Keywords: Stroke type discrimination · Cerebral hemorrhage · Cerebral ischemia · Microwave detection · Support Vector Machine

1 Introduction

The treatments of hemorrhagic stroke and ischemic stroke are significantly different, which make the stroke type diagnosis imperative before treatment (Lancet 2015). According to European clinical guideline (Committee 2008; Appelros 2015), within 4.5 h after ischemic stroke, it is the golden period of receiving thrombolytic therapy. Therefore, it is of great significance to develop an instrument for pre-hospital stroke type diagnosis which is portable, fast, and easy to operate.

Recently, mobile CT (Computed Tomography) equipment has been used for pre-hospital stroke diagnosis (Gierhake 2013; John et al. 2016). It significantly shortens the

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intervening time between ischemic stroke attack and thrombolytic therapy (Fassbender et al. 2013), but its application is limited by the medical vehicles it installed, the required professional medical staff, the stable environment and good communication. Also, it can't be used to continuously monitor rapid pathologic lesions in the acute phase of stroke. Transcranial doppler ultrasound (TCD), Near infrared spectroscopy (NIR) can be used for continuously monitoring in neurocritical intensive care unit (N-ICU) to detect large-scale vascular occlusion of stroke (Schlachetzki et al. 2012; Nakae 2012; Erdoes et al. 2018). But these methods are difficult to detect accurately when the vascular is small or the position is deep, and also cannot be used to identify bleeding caused by ischemic. Electrical impedance tomography (EIT) has been reported to detect cerebral hemorrhagic in animal experiments (Xu 2010), and to detect intracranial tissue displacement caused by stroke (Bonmassar et al. 2010). However, the measurement accuracy is easily affected by the contact resistance and the high resistivity of the skull. Microwave imaging technology has been gradually applied to brain function monitoring after several decades of development (Crocco 2018). Unlike its research applications in breast cancer detection (Byrne et al. 2017; Chen et al. 2016), the complex structure of the brain limits the imaging quality of its disease diagnosis. Therefore, using microwave scattering parameters to discriminate stroke type without imaging deserves studying.

This study combines microwave detection and pattern recognition method to rapidly diagnose and monitor stroke type without imaging of brain. This study has the following innovations, (1) A new parameter Euclidean distance is proposed here mapping the original scattering parameters, which improves the discrimination between hemorrhagic stroke and ischemic stroke. (2) Before the SVM classification, we firstly carry out the dimensionality reduction to improve the diagnostic accuracy and the efficiency of the classifier. (3) The in vivo animal experiment under controlled conditions is validated by the microwave-based stroke detection system, which not only diagnoses the type of stroke but also monitors the development of stroke.

Based on the multi-channel detection system in this study, it realizes the classification of different types and different degrees of stroke in rabbit model with discrimination accuracy of 90%. Experiments have shown that different degrees of cerebral hemorrhage and ischemia will lead to differences in microwave reflection signals, which demonstrate the feasibility of non-contact discrimination of stroke types and stroke severity based on electromagnetic properties of brain tissue.

2 Methodology

2.1 Detection Principle

The theoretical basis for the microwave reflection detection is to detect dielectric properties of different tissues in brain (Peyman et al. 2007; Schmid et al. 2003). Under pathological conditions, these changes in dielectric properties cause changes in reflection parameters.

2.2 Detection System

To detect the spatial electromagnetic properties of the whole brain, a multi-channel microwave measurement system is built here. The system is mainly composed of an antenna array sensor, a microwave monitoring device and a multiplexing switch controlled by a computer, connection as Fig. 1 shown.

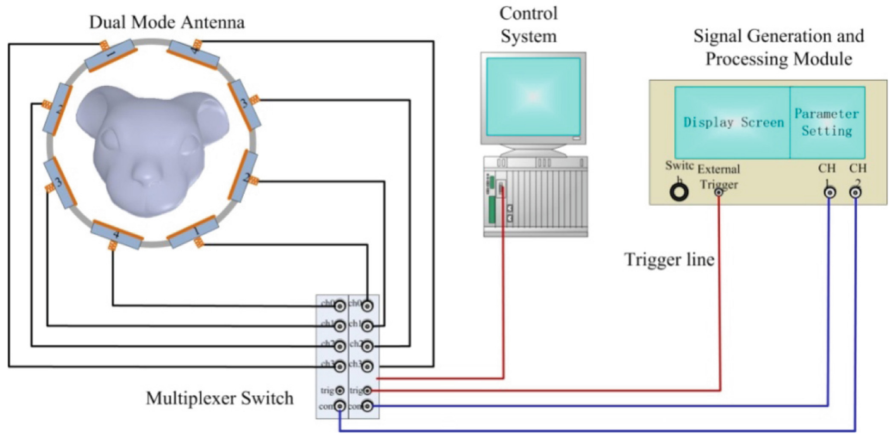

Fig. 1. System schematic

The antenna array is composed of 8 microwave patch antennas (4 Receiver and 4 Transmitter) which fixed on an acrylic loop, as shown in Fig. 1. The multiplexer switch controls 16 channels (4 Receiver × 4 Transmitter) in turn to launch the microwave measurement system. The measurement frequency ranges from 300 kHz to 3 GHz. The rabbit head is placed in the center of the sensor array during experiment, and the active antenna emits microwave through it. By detecting the reflected microwave, the parameters of the measured object are calculated, which reflect the dielectric properties of the object.

2.3 Experimental Process

Detection of cerebral hemorrhage model
The cerebral hemorrhage rabbit (inner capsule cerebral hemorrhage model) is placed on the measuring platform, and the data is measured before the blood injection as the origin experimental data (0 ml). Blood injected with the pump, and 1 ml blood is injected within 1 min. When each injection is completed (1 ml), the data is recorded and stored. The steps are repeated to complete the data acquisition at 2, 3, and 4 ml.

Detection of cerebral ischemia model
After ischemic model of bilateral carotid artery ligation, rabbits are placed on the measurement platform. The initial (0 min) ischemic data is recorded and saved at this time. Then set the multiplexer switch to automatically measure 1 time every 6 min. The measurement is repeated 6 times and the total recording time is 42 min.

2.4 Classification Algorithm

The number of samples in this experiment is small. The statistical learning theory is suitable for small sample cases according to machine learning theory. Therefore, we choose the SVM classification algorithm based on statistical learning. This paper mainly uses the LIBSVM toolkit provided by Chih-Chung Chang and Chih-Jen Lin (Fan et al. 2005; Chang and Lin 2011), and compares different parameters affecting classification accuracy.

3 Results

Since the cerebral hemorrhage model and cerebral ischemia model are different, and the pathological mechanisms are different, the data of hemorrhage (maximum 4 ml, minimum 1 ml) and ischemia (maximum 42 min, minimum 6 min) are discriminated here, preliminarily. The classification results are shown in Fig. 2. It can be seen that for the classification of hemorrhage and ischemia, the classification accuracy is above 85%, and a higher classification accuracy is achieved under linear kernel function.

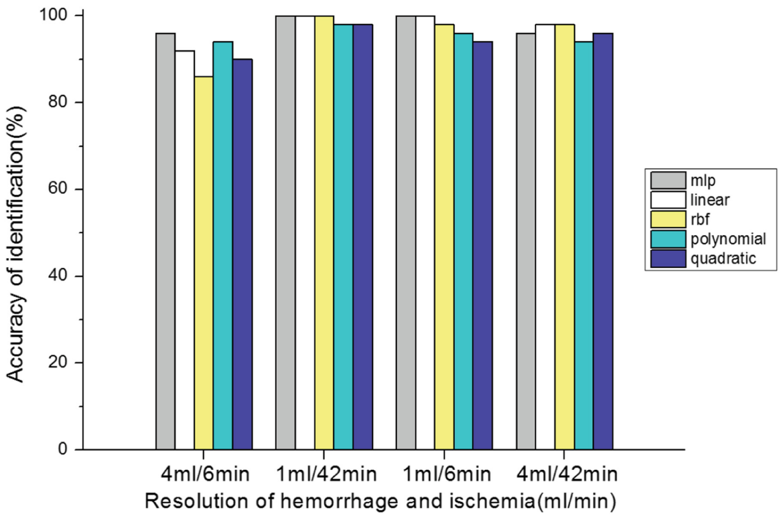

Fig. 2. Classification of bleeding and ischemia by different nuclear functions

4 Conclusions

Based on the multi-channel detection system described in this study, this paper realizes the classification of different types and different degrees of stroke on rabbit models with 90% identification accuracy. Experiments have shown that different degrees of cerebral hemorrhage and ischemia will lead to differences in microwave reflection signals, which confirm the feasibility of non-contact discrimination of stroke types based on electromagnetic properties of brain tissue. It is indicated that the electromagnetic-based method for detecting stroke is a very promising method. There will be more stroke patients benefit from its portability and low cost. And it is hopeful that more cerebral ischemia patients will be received timely thrombolytic therapy. At the same time, it indicates that the data preprocessing, the selection of classification features and the classifier are the critical factors to determine the final detection accuracy in the research.

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