IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 4 January 2024, accepted 25 January 2024, date of publication 19 February 2024, date of current version 23 February 2024.
Digital Object Identifier 10.1109/ACCESS.2024.3359717

RESEARCH ARTICLE

Design and Performance Evaluation of a Home-Based Automatic Acupoint Identification and Treatment System

ZHENG YU[1], SHENGYAN ZHANG[1], LINSHUAI ZHANG[1,2], CHUANBIAO WEN[1], SHUGUANG YU[1], JIAQI SUN[1], SUHENG DENG[1], HONGFU CI[1], AND YANXIONG GAN[1]
[1]School of Intelligent Medicine, Chengdu University of Traditional Chinese Medicine, Chengdu, Sichuan 611137, China
[2]School of Automation, Chengdu University of Information Technology, Chengdu, Sichuan 610103, China

Corresponding authors: Linshuai Zhang (zhanglinshuai@cdutcm.edu.cn) and Chuanbiao Wen (228237222@qq.com)

This work was supported in part by the Innovation Team and Talents Cultivation Program of National Administration of Traditional Chinese Medicine under Grant ZYYCXTD-D-202003, in part by the Science and Technology Department of Sichuan Province under Grant 2022YFS0036, in part by the Sichuan Science and Technology Planning Project under Grant 2023YFG0178, and in part by the Science and Technology Innovation Ability Improvement Plan of Cheng University of Information Technology under Grant KYTD202228.

ABSTRACT Acupuncture can be effective in relieving pain and reducing drug dependence and abuse caused by chronic pain. However, the cumulative effect of acupuncture requires patients to undergo multiple treatments, which limits its use due to time and economic costs. Currently, existing acupuncture devices include acupoint identification and acupoint stimulation devices. The identification and stimulation functions are separated for these two classes of devices. They were unable to locate the acupoint automatically and required a professional acupuncturist to perform the procedure. Although acupuncture robots that can simultaneously identify the acupoints and initiate treatment are under development, the technology is not yet mature that it is currently not available for general use. To address these issues, we developed an automatic system that combines the identification of acupoints and the administration of treatment. The system is designed to assist users without any knowledge of acupuncture in the management of chronic pain at home. We conducted tests to evaluate the performance of the system in terms of resistance detection accuracy, electroacupuncture accuracy, and acupoint identification test. The results demonstrate that the system significantly improves the accuracy of locating acupoints, indicating its suitability for daily home use as an effective approach to managing chronic pain.

INDEX TERMS Acupoint identification, electroacupuncture, home-based automatic acupoint identification and treatment system, resistance detection.

I. INTRODUCTION

Chronic pain creates a significant personal and financial burden, affecting more than 30% of people worldwide [1]. The Global Burden of Disease Study indicates that the high prevalence of pain and pain-related diseases is the leading cause of disability [2]. It also affects relationships and self-esteem, increasing divorce rates and even reducing life expectancy [1], [3]. Studies have shown that chronic pain alters brain activity, including endogenous pain control, suggesting that control of pain becomes more difficult as it becomes chronic [4]. Clinical trials and guidelines generally recommend the cautious use of analgesics, physical therapy, and psychotherapy [5]. But the truth is, analgesics are wildly overused. We can see that the prescribing of opioid analgesics for pain management, particularly for chronic non-cancer pain management, has more than quadrupled in the United States since the mid-1990s [6], [7], [8]. Adjusting for country of residence and sociodemographic factors, it was found that analgesic abuse was not limited to the United States, with France, the United Kingdom, Germany and Australia also facing the same intractable problem [9]. The abuse of

The associate editor coordinating the review of this manuscript and approving it for publication was Rajeswari Sundararajan.

analgesics affects more than 9% of patients [10]. This directly leads to addiction and overdose deaths [6]. Using physical therapy as an alternative to analgesics is an effective approach to reducing drug abuse and alleviating pain.

A. RELATED WORK

Acupuncture is effective in treating chronic pain, which is an ancient science with a history of more than 3,000 years [11]. It is currently the most popular alternative therapy in the United States, Europe and Asia [12], [13]. Numerous studies have shown the beneficial effects of acupuncture on the treatment of chronic pain, such as osteoarthritis, back pain, neck pain, headaches [14], and post-operative pain [15]. It is particularly noteworthy that acupuncture has a long-lasting and preventive effect [16], [17], [18], [19]. A meta-analysis found that the effect of a single course of acupuncture therapy for patients with chronic pain did not appear to decrease significantly over 12 months [19]. Our previous large clinical study has shown that regular acupuncture can effectively reduce the frequency and severity of migraine attacks [20]. However, the cumulative effect of acupuncture requires the patient to undergo multiple treatments, which considerably increases the time and financial cost to the patient, and is an essential reason why most patients are unable to adhere to the treatment. Therefore, the development of an automated acupuncture treatment device that can be used at home is necessary.

Currently, the more commonly used acupuncture devices can be categorized into two main types: acupoint identification and acupoint stimulation. The identification device is capable of locating or capturing changes in acupoints by detecting their physical state and chemical changes. For instance, electroacupuncture according to Voll can detect acupoints. Other inventors have also claimed to identify health problems using similar devices [21], but this function has been questioned by the scientific community [22]. Shima et al. developed a four-electrode device system that enables stable measurement of electrical skin impedance in acupuncture [23]. Yang and Xia designed an acupoint recognition device by improving the acupoint electric resistance detection technique of the two-electrode method in combination with mechanical structure design and embedded control techniques [24]. Wong et al. introduced an electrical impedance device to study the impedance of meridian and non-meridian tissue segments using an old and little-known impedance measurement technique. The device consists of a Fluke meter, a multiplexer box, a laptop computer, and a medical-grade isolation transformer. This device has demonstrated potential for use in quantifying the degree of electrical interconnection between any two surface-defined test meridian or non-meridian segments [25]. Su et al. use a five-electrode technique for bilaterally symmetrical acupoints impedance simultaneous measurement. Based on these five-electrode techniques, measurement errors due to unstable electrode contact impedances can be greatly reduced [26]. Such detection devices are collectively referred to as electrodermal screening devices. According to the characteristics of low resistance and high potential of meridians, the acupoints or meridians were detected. All the above studies validate the feasibility of two-, four-, or multi-electrode detection techniques in acupoint identification. Another type of identification device captures changes in the acupoint and is used to study the mechanism of acupuncture. Xu et al. used a fine wire thermocouple embedded in a hollow needle as an acupoint detection probe for acquiring temperature data [27], while Tang et al. reported using an acupuncture needle modified with an iron-porphyrin functionalized graphene composite (FGPC) for real-time monitoring of nitric oxide (NO) release in rat acupoints [28].

Compared with traditional acupuncture needles, the stimulation devices adopted electricity or laser to achieve a therapy effect. The most common device for stimulating acupoints is electroacupuncture, which combines electrical stimulation with traditional acupuncture needles to achieve accurate control over the stimulus quantity. First, the acupuncture practitioner inserts the needles into the acupoints and then connects them to positive and negative poles to initiate treatment. Transcutaneous electrical acupoint stimulation (TEAS) is used to treat different kinds of disease [29], [30], [31]. It uses self-adhesive electrodes placed on the surface of acupoints, instead of needles for electrical stimulation, and effectively for pain release [32]. Laser acupuncture including blue, red and infrared laser light is a device developed in recent years for acupuncture treatment with the development of science and technology [33]. Chang et al. developed a new laser acupuncture system that uses a semiconductor laser tube as the light source. The focus of the laser beam was adjusted by changing the position of the lens to mimic the effect of lifting and thrusting in traditional acupuncture [34]. Litscher et al. through their research found that continuous 405 nm blue laser light stimulation significantly reduces the heart rate of Chinese adults applied on Neiguan [35]. Wen et al., on another note, achieved moxibustion's warming effect by stimulating acupoints with infrared light [36]. Additionally, many researchers have developed other therapeutic devices based on acupuncture theory and therapeutic characteristics; one example being Sator-Katzenschlager et al.'s development of a P-Stim auricular electroacupuncture stimulation device for pain relief [37].

Another important research direction for acupuncture treatment devices is acupuncture robots. The robot can automatically locate and stimulate the acupoint with a mechanical arm [38]. Some researchers believe that in the future, laser stimulation technology, machine learning algorithms and computer visualization technology will be integrated to develop acupuncture robots [39]. However, at present, research on acupuncture robots is still in its infancy, and current literature reports mainly focus on the localization of acupoints. For example, Chan et al. combined deep learning and an anatomical inch measurement approach to robotic acupuncture point positioning [40]. There are still some critical technical issues in the development of acupuncture robots, such as inaccurate acupoint localization and the inability to sense the operational state in real-time. At the core of competition among all research and development institutions are algorithms behind acupoint diagnosis techniques, automatic positioning of acupoints, syndrome differentiation and acupoint matching functions even force feedback functions. The research and development of intelligent acupuncture robots is still in the laboratory stage. It still has a long way to go before it is truly popularized for home use.

The above device is characterized as follows: (1) The functions of acupoint detection and stimulation are separated; (2) Unable to locate acupoints automatically, the operation of detecting acupoints is complicated and time-consuming; (3) Conventional sensors used for impedance detection are large and hard, which is not conducive to being fixed to the surface of the body; (4) Acupuncture needle sensors are invasive; (5) Professional acupuncturists are required for the procedure; (6) The cost of the acupuncture robot is high, and the technology is not mature, so it cannot be popularized.

B. OUR CONTRIBUTION

In order to address the above problems, we developed a home-based automatic acupoint identification and treatment system. It can automatically locate acupoints and has the therapeutic function, which is suitable for the daily treatment of chronic pain. There are four main contributions of the present study. First, the system can automatically locate acupoints and integrate therapeutic functions, which can be easily used by anyone who is even without any knowledge of acupuncture theory. Second, the device uses a self-developed flexible integrated sensor to integrate detection and treatment functions. It can closely fit the skin and improve the accuracy of detection. Third, it is multi-channel designed so that nine acupoints can be located simultaneously, thus enabling synergistic effects. Fourth, it is small and easy to move, making it suitable for home healthcare.

II. SYSTEM DESCRIPTION

We have developed a home-based automatic acupoint identification and treatment system that is capable of automatically locating and stimulating the acupoints simultaneously to relieve chronic pain. The system consists of three main components: the upper PC, the device, and the integrated sensor unit. The upper PC displays the operation control interface. The primary and secondary operating systems are used on the device side. The main control circuits of the primary and secondary subsystems adopt STM32F105RCT6 and STM32F072C8T6 as the main control chips, cooperating with the self-developed embedded algorithm based on the chain list structure of the C language, which can effectively process a large number of data, realize the parallel detection of 9-channel acupoint status. It can access real-time resistance data collected by sensors uploaded through a USB interface, enabling the host PC to quickly obtain data from

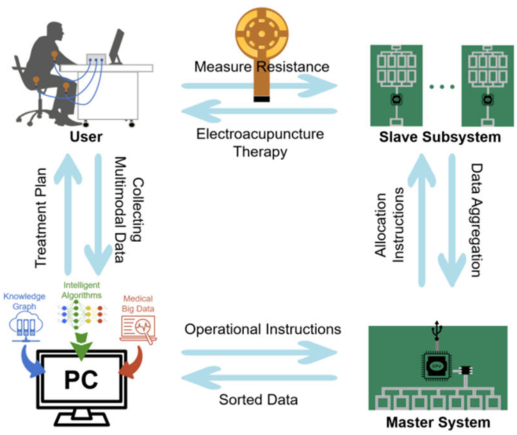


FIGURE 1. Overview of home-based automatic acupuncture point identification and treatment system.

the message queue and process it sequentially, thus ensuring an orderly consumption of messages. Administrators can observe the dynamics of the data in real-time on the upper PC to accurately locate the acupoints and give reasonable electroacupuncture intervention procedures based on the embedded self-developed model of the acupoints discrimination algorithm.

The administrator issues instructions for the electroacupuncture system through the upper PC, which are assigned by the primary subsystem to the corresponding secondary subsystem to complete the treatment.

III. ACCURATE ACUPOINT POSITIONING AND TREATMENT MECHANISM

A. STRUCTURE OF INTEGRATED FLEXIBLE SENSOR

Accurate acupoint positioning is fundamental to the efficacy of acupuncture. Traditionally, TCM practitioners rely on several methods such as bone measurements, body surface markers, and cun measurements to locate various acupoints [41]. Acupuncturists need repeated training to remember the locations of more than 400 acupoints, which is not suitable for people who want to treat themselves with acupuncture at home. For people without professional training in acupuncture, approximate locations of the acupoints can be found based on the text descriptions and the diagram, but there will certainly be some errors and it will not be possible to locate them accurately. Based on the low resistance characteristic of acupoints, we developed an acupoint resistance detection sensor [42], [43], [44], [45]. The sensor consists of an excitation source, a conversion circuit, an electrode part, and a digital-to-analog converter. It has been pointed out in literature that the acupoint region is in general a circular area of radius 0.5 cm with the center of the localization point on the surface of the acupoint [46]. Our sensor has eight electrodes, each of which forms a current path with the center of the circle. The distance between the electrodes and the center of the sensor is 2 cm to ensure that the acupoint can be covered. During the detection process, when the resistance value of a certain pathway is detected to be relatively low, the built-in algorithm determines that the point lies between the detection electrode and the center of the circle. Because one sensor has eight detection electrodes, the device is able to detect the surrounding points even if the sensor deviates from the actual location of the acupoint.

In this way, the sensor can simultaneously detect eight points in an area of about 12.56cm^2, thereby increasing the rate of correctly locating the acupoint (Figure 2). After the algorithm determines the location of the specific acupoint, the four electroacupuncture electrodes on the outer ring of the sensor can be mobilized, and the main control can issue commands to carry out random pairwise combinations to treat the found acupoint.

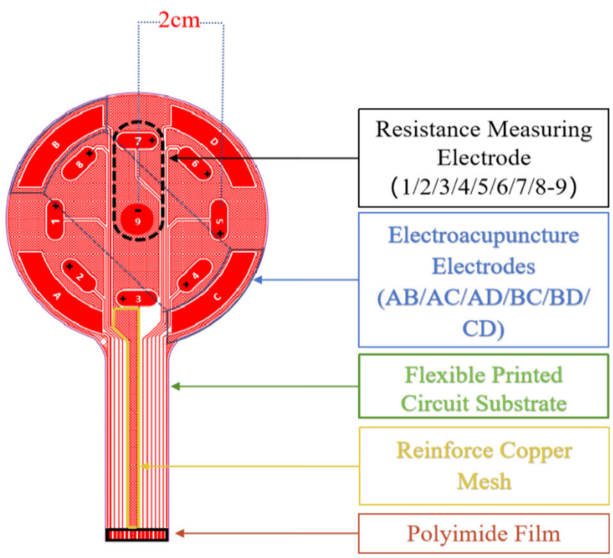


FIGURE 2. The integrated sensor for resistance detection and transcutaneous electrical stimulation. 1∼9 were the detection electrodes, 1∼8 each of which forms a current path with 9; A∼D were randomly combined in pairs to form transcutaneous electrical stimulation. The inner ring detection electrode radius was 2cm.

The excitation source gives a constant excitation signal and supplies power to the electrode through an inverted circuit. A path is connected to the inner ring resistance detection electrode with the acupoint skin to form a loop, which receives the feedback change signal of the partial pressure node and converts it into the corresponding ADC value through a 12-bit digital-to-analog converter. The ADC value and the acupoint resistance value are converted by Ohm's law formula, and the specific formula is as follows:

$$R_x = \frac{V_x}{V_9 - V_x} \times 103\text{k}\Omega$$

where 103kΩ is the sub-piezoelectric resistance value, V9 is the reference ADC value, and VX is the corresponding ADC value of each detection electrode.

The other pathway connects with the pulse amplification circuit and the acupuncture electrode, which simulates the transcutaneous electrical stimulation to treat the acupoints. Transcutaneous electrical acupoint stimulation is widely used in the clinical treatment of a variety of diseases [32], [47]. The needle electrode was a wet electrode and was used after placing the hydrogel. The main control system controls the triode switch to charge and discharge the inductor, and then forms the electrical stimulation signal of low frequency, high voltage and low current. By adjusting the parameters such as waveform, intensity and frequency, simulating acupuncture manipulation.

B. SENSOR-BASED CONTROL SYSTEM

The control system consists of a primary subsystem and a secondary subsystem, forming a closed-loop structure. The primary subsystem is composed of a signal transduction module and a function control module. Its function is to sequentially transmit resistive data collected from the subsystem to the PC and receive, split, or execute control instructions from the PC, which are then passed down to the secondary subsystem. The secondary subsystem is made up of a signal transduction module, a main control module, a basic electroacupuncture unit, and a resistance detection unit. Its functions include two aspects. One is to receive instructions from the primary subsystem, to control the relay module of the basic electroacupuncture unit according to the instruction content, to complete the operation of voltage conversion and power amplifier, to output electrical stimuli with different waveforms and frequencies, or to control the working state of the resistive detection unit. Second, it receives the resistance data collected by the sensors and calculates the resistance value, which is sent back to the primary subsystem. The primary subsystem then sends the data to the PC for reception, analysis and storage (Figure. 3).

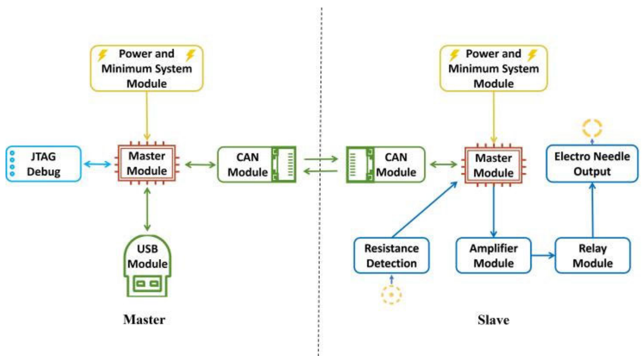


FIGURE 3. Schematic diagram of home-based automatic acupuncture point identification and treatment device.

The operation of the Microprogrammed Control Unit (MCU) is shown in Figure 4. The sensor input signals, then after signal filtering, analog-to-digital conversion, amplification, and other processing, the input processor transmits the signal to the MCU for operational processing. The resistance values collected by the sensor electrodes are obtained and a built-in algorithm is used to determine whether the detected point is an acupoint, which is excited through the stimulus electrodes. The output processor then performs power amplification and digital-to-analog conversion of the

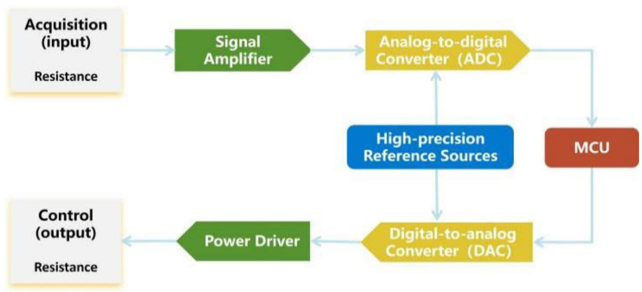


FIGURE 4. Schematic diagram of signal acquisition and intervention.

signal to obtain the resistance values collected by the sensor electrodes. The built-in algorithm determines whether the detection point is an acupoint or not, while the acupoint is stimulated by the stimulus electrode.

The resistance-type transducer module and the electrical stimulation module are in the power-saving state by default. To perform a measurement, the user sends a measurement command to the controller, and after the resistance measurement or electrical stimulus operation is completed, the module automatically enters a power-saving state until the next command is initiated. The timer chosen in this device is a programmable timer, the timing length can be controlled by a user program, and the application is very flexible. The device uses a self-developed embedding algorithm based on the linked list structure of the C language for parallel detection of 9-channel acupoint states.

IV. EXPERIMENTAL EVALUATION

A. RESISTANCE DETECTING ACCURACY ASSESSMENT

In order to verify the accuracy of the device for resistance detection, we built a test platform that consists of a Fluke 17B+ digital multimeter (FDM), plug-in fixed resistors (20KΩ, 51KΩ, 100KΩ, 300KΩ), and a computer (Figure 5).

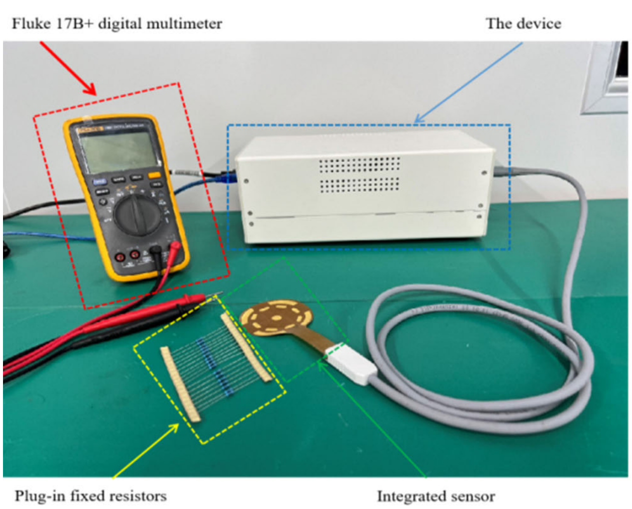


FIGURE 5. The experimental setup for resistance detecting accuracy assessment.

At room temperature of 25°C, the second, fourth, sixth and eighth electrode were selected to measure the resistance of the patch, and compared with the value measured by FDM (Table 1, Figure 6).

TABLE 1. The experimental results for resistance detecting accuracy assessment.

	20KΩ	51KΩ	100KΩ	300KΩ
FDM	19.911KΩ	50.871KΩ	99.364KΩ	305.831KΩ
Electrode 2	17.886KΩ	48.116KΩ	96.665KΩ	297.464KΩ
Electrode 4	17.879KΩ	47.883KΩ	96.762KΩ	296.394KΩ
Electrode 6	17.965KΩ	47.731KΩ	97.081KΩ	296.201KΩ
Electrode 8	17.954KΩ	48.103KΩ	97.101KΩ	296.412KΩ

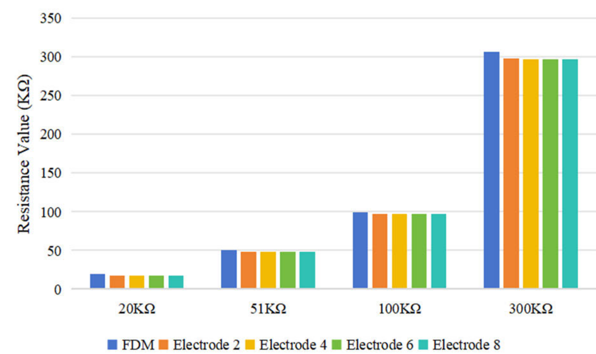


FIGURE 6. Precision of resistance detection for sensors with different electrodes.

The result shows that the resistance detection error is between 2KΩ and 4KΩ. Therefore, the error is within the acceptable range.

B. ELECTROACUPUNCTURE ACCURACY ASSESSMENT

The way to test the accuracy of electroacupuncture frequency is by setting the electroacupuncture to a specific frequency and performing a comparison test. Dingyang SDS1000A digital oscilloscope was used to evaluate the electroacupuncture function (Figure 7). We did a test three times, and the results are shown in Table 2 and Figure 8.

V. VALIDATION TRAILS

A. PARTICIPANT

To further demonstrate the performance of the proposed system in acupoint identification, trials were performed with 50 different subjects. All subjects in this study have to meet the study have to meet the inclusion criteria:(1) without any acupuncture training background; (2) have literacy ability. The exclusion criteria were as follows: (1) mental illness, or severe psychiatric disorders; (2) pregnant, preparing for pregnancy, or breastfeeding. All participants were instructed to complete a cognitive assessment using the Chinese version

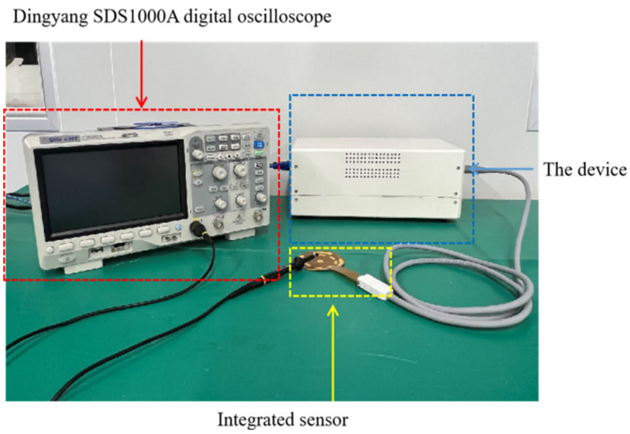


FIGURE 7. **The experimental setup for electroacupuncture accuracy assessment.**

TABLE 2. **Experimental results for the accuracy test of electroacupuncture.**

	2Hz	4Hz	6Hz	8Hz	10Hz	12Hz	14Hz	16Hz	18Hz	20Hz
Standard Control	2	4	6	8	10	12	14	16	18	20
Test 1	1.22	3.58	5.58	7.93	10.21	12.58	13.97	16.28	17.89	20.33
Test 2	1.17	3.05	5.47	7.66	10.52	11.97	13.88	15.53	17.78	21.08
Test 3	1.47	3.42	5.78	7.83	10.67	12.03	14.01	15.82	17.93	21.01

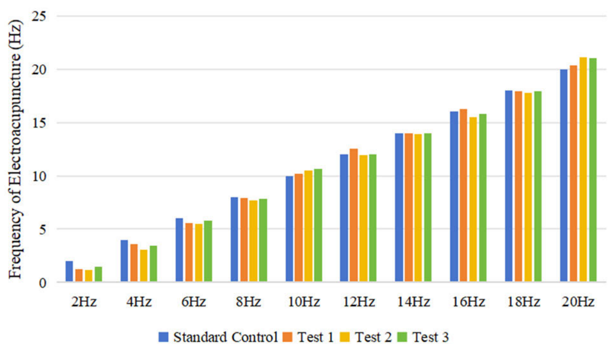


FIGURE 8. **Electroacupuncture accuracy between the device and the standard control.**

of the Montreal Cognitive Assessment test (MoCA) before the positioning acupoints, to make sure all subjects with similar levels of cognitive competence. The advantage of this experimental design is that it provides a clear, unbiased comparison of performance because it eliminates any learning bias. The experimental task was to have subjects locate acupoints. 50 subjects were divided into the Device Positioning Acupoints group (DPA) and the control group. The accuracy of acupoints' location is the metric considered in this experiment.

B. POSITIONING ACUPOINTS AND RESULTS

Nine acupoints were randomly selected on the lower limbs for volunteers to locate. The nine acupoints were:

GB30: Located in the gluteal region at the intersection of the outer 1/3 and inner 2/3 of the line between the most convex point of the greater trochanter of the femur and the hiatus of the sacral canal.

GB33: Located on the lateral side of the knee, in the depression above the lateral epicondyle of the femur.

GB34: Located on the lateral side of the calf, in the anterior and lower depression of the fibula.

GB39: Located three inches above the tip of the lateral ankle, leading edge of the fibula.

ST36: Located anterolateral to the lower leg, one finger across from the leading edge of the tibia.

SP6: On the inside of the calf, three inches above the tip of the medial malleolus, behind the medial border of the tibia.

SP10: Located in the anterior femoral region, 2 inches above the medial end of the patellar base, at the eminence of the medial femoral muscle.

SP11: Located in the anterior femoral region, at the intersection of upper 1/3 and lower 2/3 of the line between the medial end of the patellar base and the gate, the artery pulsates at the intersection of the adductor longus and sartorius muscles.

KI10: Located in the depression between the medial condylar border of the tibia and the medial border of the tibia (Figure 9).

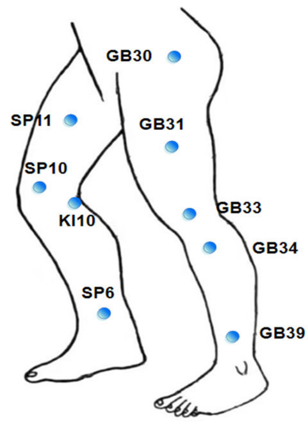


FIGURE 9. **Schematic diagram of acupoint location.**

TABLE 3. **Comparison of baseline characteristics.**

Characteristic	DPA group (n = 25)	Control group (n = 25)	*T/X2*	*p*-value
Age	26.48±2.53	27.6±2.66	-1.52	0.13
Sex (female)	46.20%	53.80%	0.32	0.57
MoCA (total score)	28.24±1.13	28.16±1.14	0.25	0.8

The DPA group uses the proposed device to place and fix the sensor based on the position of the acupoint indicated by the graph in the operating system, and then initiate the detection. In the control group, the acupoints were located

TABLE 4. Accuracy of positioning of 9 acupoints between the DAP and control group.

Acupoint	Group	Total (n)	Accurate positioning rate [n(%)]	Non-accurate positioning rate [n(%)]	X^2	*p-value*
GB30	DPA group	25	19(76%)	6(24%)	9.74	0.002
	Control group	25	8(32%)	17(68%)		
GB31	DPA group	25	22(88%)	3(12%)	12.5	0
	Control group	25	10(40%)	15(60%)		
GB33	DPA group	25	21(84%)	4(16%)	5.88	0.007
	Control group	25	13(52%)	12(48%)		
GB34	DPA group	25	20(80%)	5(20%)	6.87	0.009
	Control group	25	11(44%)	14(56%)		
GB39	DPA group	25	20(80%)	5(20%)	8.33	0.004
	Control group	25	10(40%)	15(60%)		
SP6	DPA group	25	19(76%)	6(24%)	5.33	0.021
	Control group	25	11(44%)	14(56%)		
SP10	DPA group	25	20(80%)	5(20%)	8.33	0.004
	Control group	25	10(40%)	15(60%)		
SP11	DPA group	25	17(68%)	8(32%)	3.94	0.047
	Control group	25	10(40%)	15(60%)		
KI10	DPA group	25	17(68%)	8(32%)	6.48	0.011
	Control group	25	8(32%)	17(68%)		

according to the same graph and text instructions. After the experiment, the accuracy of localization was judged by two experienced acupuncturists, marking '1' if the acupoints were correctly located, and '0' if they were not.

We compared the baseline characteristics between the DPA and the control group. The age, sex and MoCA scores were similar between the two groups (all p values > 0.05; Table 3) indicates that subjects are comparable between the two groups.

Based on the results summarized in Table 4, the accurate positioning rate in the DPA group was significantly higher than the control group ($P < 0.05$). Without the aid of the system described above, the acupoint localization accuracy of the control group was below 50%, but after the system correction, it increased significantly. This suggests that the system can effectively help users adopt acupuncture treatment at home, even though they may know nothing about it, and thereby alleviate chronic pain. (Table 4).

VI. DISCUSSION

Acupuncture has been found to effectively alleviate chronic pain compared to sham-acupuncture and no-acupuncture control groups, with response rates of approximately 30% for no-acupuncture, 42.5% for sham acupuncture, and 50% for acupuncture [48]. The mechanism of pain relief through electroacupuncture involves the activation of various bioactive chemicals through peripheral, spinal, and supraspinal pathways. Furthermore, combining electroacupuncture with low doses of conventional analgesics offers effective pain management while minimizing the side effects associated with high-dose pharmaceuticals [49]. Accurate acupoint location is crucial for successful acupuncture treatment, and the analgesic effect of non-acupoints is significantly reduced [50]. Therefore, acupuncture treatments have to be administered by skilled acupuncturists. The development of a home-based acupuncture device that can accurately locate acupoints and provide therapeutic functions may be a valuable tool for pain management and reducing reliance on painkillers.

In this work, we proposed a home-based automatic acupoint identification and treatment system. Using a primary-secondary design, the system is able to simultaneously detect the resistance of the nine points in parallel and accurately locate the acupoints through a built-in self-developed acupoint identification algorithm. Based on the detection results, transcutaneous electrical stimulation was performed at the acupoints. We tested the accuracy of resistance detection, the result shows that the resistance detection error is between 2KΩ and 4KΩ. The resistance of acupoint is between 30KΩ and 500 kΩ [51]. Therefore, the error is within the acceptable range. We also performed an accuracy test on electroacupuncture treatments. The results show that the errors between the mean values of the three measured frequencies and the standard frequency range from 0.05 to 0.8 Hz. An error value of 0.8 Hz was observed for the electroacupuncture frequency of 20 Hz. However, at the standard frequency of 2 Hz, our device demonstrates an error of 0.7 Hz, which is suboptimal and requires further improvement. Fei-Peng et al. examined several electroacupuncture devices and found significant discrepancies between the actual operating frequency and the flagged frequency, with most errors exceeding 50% [52]. It is evident that our device exhibits a higher level of accuracy compared to the majority of devices currently available on the market. Subsequent clinical trials were conducted, revealing that the control group had an acupoint localization accuracy below 50% without the assistance of the proposed system. However, after using the system for correction, there was a significant increase in accuracy. This demonstrates that the implementation of the proposed system among volunteers without any background in acupuncture training resulted in a substantial improvement in the accuracy of acupuncture point locations.

At present, the most widely known devices for acupoint positioning based on impedance detection are electroacupuncture according to Voll (EAV) [53] and SVESA neural pen [54]. In EAV the electrical conductance of the skin above individual acupuncture points is measured using low voltage and current. Diagnosis depends on measuring the relative electrical conductance and its time dependence [55]. SVESA neural pen can detect auricular acupoints by placing the thin tip of the pen vertically on the surface of the skin, the ear can be systematically scanned. The electrical impedance conversion at a region with altered skin resistance is visualized via the red light-emitting diode, thus enabling the detection of auricular acupuncture points by measuring the electrical skin resistance with a neural pen [54]. The aforementioned devices can not satisfy clinical applications. EVA has low efficiency, and SVESA is limited to auricular points. As a result, researchers are striving to develop more efficient devices for exploring acupoints. Yang and Xia developed an embedded acupoint recognition device and resistance detection is achieved through the magnetic head at the top of the device [24]. Ma et al. designed an acupoint resistance detection system based on Cole's three-element equivalent circuit model with acupuncture needles as electrodes [56]. However, the mentioned devices are in the theoretical stage and no validation tests are mentioned in the literature, so their detection accuracy is not known. Furthermore, unlike the mentioned devices that require manual handling and can only detect one acupoint at a time, our device has the advantage of simultaneously detecting 9 acupoints. This simultaneous detection capability significantly enhances overall detection efficiency. In addition to the impedance measurement method, the integration of multiple machine learning algorithms and computer vision techniques for acupoint positioning has emerged as a prominent research area [40], [41], [57]. Nevertheless, existing research outcomes primarily concentrate on the recognition of hand and face acupoints, lacking comprehensive coverage of the entire body. Therefore, our developed system holds the advantage of integrating multiple functions and boasts a broad range of applications.

VII. CONCLUSION

To summarize, our home-based automatic acupoint identification and treatment system integrates detection and treatment functions. Through rigorous testing, we have verified its feasibility, stability, and its ability to effectively locate acupoints. This system significantly reduces operational difficulties and enhances the accuracy of acupoint localization. It is cost-effective, compact, and suitable for daily home use, offering an effective approach to managing chronic pain. The current work was limited in several respects, and these limitations highlight important avenues for future research. First, this system can only detect acupoint resistance, but temperature is also an important physical parameter of acupoints; second, the device only has the function of electroacupuncture, but moxibustion is recognized as one of the effective treatments for chronic pain. Therefore, the next research direction for our team involves incorporating temperature detection and moxibustion treatment functions into the system.

Author Contributions: Conceptualization, Zheng Yu; Funding acquisition, Zheng Yu and Linshuai Zhang; Methodology, Shuguang Yu and Chuanbiao Wen; Validation, Shengyan Zhang, Jiaqi Sun, Suheng Deng, and Hongfu Ci; Writing–original draft, Zheng Yu and Shengyan Zhang; Writing–review and editing, Linshuai Zhang.

Conflicts of Interest: The authors declare no conflict of interest.

ACKNOWLEDGMENT

(Zheng Yu and Shengyan Zhang are co-first authors.)

REFERENCES

[1] S. P. Cohen, L. Vase, and W. M. Hooten, "Chronic pain: An update on burden, best practices, and new advances," *Lancet*, vol. 397, pp. 2082–2097, May 2021.

[2] G. B. D. Disease, I. Injury, and C. Prevalence, "Global, regional, and national incidence, prevalence, and years lived with disability for 328 diseases and injuries for 195 countries, 1990–2016: A systematic analysis for the global burden of disease study 2016," *Lancet*, vol. 390, pp. 1211–1259, Jan. 2017.

[3] S. E. E. Mills, K. P. Nicolson, and B. H. Smith, "Chronic pain: A review of its epidemiology and associated factors in population-based studies," *Brit. J. Anaesthesia*, vol. 123, no. 2, pp. 273–283, Aug. 2019.

[4] Z. Yu, R.-R. Wang, W. Wei, L.-Y. Liu, C.-B. Wen, S.-G. Yu, X.-L. Guo, and J. Yang, "A coordinate-based meta-analysis of acupuncture for chronic pain: Evidence from fMRI studies," *Frontiers Neurosci.*, vol. 16, Dec. 2022, Art. no. 1049887.

[5] N. Hylands-White, R. V. Duarte, and J. H. Raphael, "An overview of treatment approaches for chronic pain management," *Rheumatology Int.*, vol. 37, no. 1, pp. 29–42, Jan. 2017.

[6] N. Volkow, H. Benveniste, and A. T. McLellan, "Use and misuse of opioids in chronic pain," *Annu. Rev. Med.*, vol. 69, no. 1, pp. 451–465, Jan. 2018.

[7] K. E. Vowles, M. L. McEntee, P. S. Julnes, T. Frohe, J. P. Ney, and D. N. van der Goes, "Rates of opioid misuse, abuse, and addiction in chronic pain: A systematic review and data synthesis," *Pain*, vol. 156, no. 4, pp. 569–576, 2015.

[8] A. D. Kaye, S. Kandregula, J. Kosty, A. Sin, B. Guthikonda, G. E. Ghali, M. K. Craig, A. D. Pham, D. S. Reed, S. A. Gennuso, R. M. Reynolds, K. P. Ehrhardt, E. M. Cornett, and R. D. Urman, "Chronic pain and substance abuse disorders: Preoperative assessment and optimization strategies," *Best Pract. Res. Clin. Anaesthesiol.*, vol. 34, no. 2, pp. 255–267, Jun. 2020.

[9] K. I. Morley, J. A. Ferris, A. R. Winstock, and M. T. Lynskey, "Polysubstance use and misuse or abuse of prescription opioid analgesics: A multi-level analysis of international data," *Pain*, vol. 158, no. 6, pp. 1138–1144, 2017.

[10] N. Vadivelu, A. M. Kai, G. Kodumudi, D. Haddad, V. Kodumudi, N. Kuruvilla, A. D. Kaye, and R. D. Urman, "Recommendations for substance abuse and pain control in patients with chronic pain," *Current Pain Headache Rep.*, vol. 22, no. 4, p. 25, Apr. 2018.

[11] Y. Zhuang, J. Xing, J. Li, B. Y. Zeng, and F. Liang, "History of acupuncture research," *Int. Rev. Neurobiol.*, vol. 111, pp. 1–23, Jan. 2013.

[12] S. K. Kim and H. Bae, "Acupuncture and immune modulation," *Autonomic Neurosci.*, vol. 157, nos. 1–2, pp. 38–41, Oct. 2010.
[13] M. J. Mallory, A. Do, S. E. Bublitz, S. J. Veleber, B. A. Bauer, and A. Bhagra, "Puncturing the myths of acupuncture," *J. Integrative Med.*, vol. 14, no. 5, pp. 311–314, Sep. 2016.
[14] A. J. Vickers, E. A. Vertosick, G. Lewith, H. MacPherson, N. E. Foster, K. J. Sherman, D. Irnich, C. M. Witt, and K. Linde, "Acupuncture for chronic pain: Update of an individual patient data meta-analysis," *J. Pain*, vol. 19, no. 5, pp. 455–474, May 2018.
[15] H. V. Acar, "Acupuncture and related techniques during perioperative period: A literature review," *Complementary Therapies Med.*, vol. 29, pp. 48–55, Dec. 2016.
[16] A. Morehead and G. Salmon, "Efficacy of acupuncture/acupressure in the prevention and treatment of nausea and vomiting across multiple patient populations," *Nursing Clinics North Amer.*, vol. 55, no. 4, pp. 571–580, Dec. 2020.
[17] J.-B. Yang, L.-F. Wang, and Y.-F. Cao, "Advances in the prevention and treatment of postoperative delirium by acupuncture: A review," *Medicine*, vol. 102, no. 14, 2023, Art. no. e33473.
[18] H. Zheng, Y. Han, Y. Du, X. Shi, H. Huang, X. Yu, X. Tan, C. Hu, Y. Wang, and S. Zhou, "Regulation of hypertension for secondary prevention of stroke: The possible 'bridging function' of acupuncture," *Complementary Med. Res.*, vol. 25, no. 1, pp. 45–51, 2018.
[19] H. MacPherson, E. A. Vertosick, N. E. Foster, G. Lewith, K. Linde, K. J. Sherman, C. M. Witt, and A. J. Vickers, "The persistence of the effects of acupuncture after a course of treatment: A meta-analysis of patients with chronic pain," *Pain*, vol. 158, no. 5, pp. 784–793, 2017.
[20] L. Zhao, J. Chen, Y. Li, X. Sun, X. Chang, H. Zheng, B. Gong, Y. Huang, M. Yang, X. Wu, and X. Li, "The long-term effect of acupuncture for migraine prophylaxis: A randomized clinical trial," *JAMA Internal Med.*, vol. 177, no. 4, pp. 508–515, 2017.
[21] A. Oliveira, "Electroacupuncture according to Voll: Historical background and literature review," *J. Acupuncture Oriental Med.*, vol. 3, no. 1, p. 1–10, 2016.
[22] S. Barrett, "Close examination of a ZYTO electrodermal screening system," *Missouri Med.*, vol. 114, no. 4, pp. 238–244, 2017.
[23] R. Shima, Z. Jiang, S. Fen, A. Monnavar, and K. Ali, "Development and evaluation of a novel four-electrode device system for monitoring skin impedance," *Afr. J. Traditional, Complementary Alternative Medicines*, vol. 9, no. 4, pp. 599–606, Sep. 2012.
[24] X. Yang and Z. Xia, "Design of new-style embedded acupoint recognition device," *Zhongguo Zhen Jiu = Chinese Acupuncture Moxibustion*, vol. 38, no. 6, pp. 675–678, 2018.
[25] F. W. S. Wong, C. E. D. Lim, and W. Smith, "A new bioimpedance research device (BIRD) for measuring the electrical impedance of acupuncture meridians," *J. Alternative Complementary Med.*, vol. 16, no. 3, pp. 257–264, Mar. 2010.
[26] M.-Y. Su, Y.-H. Tan, C.-J. Gan, S.-H. Chen, and Z.-M. Wang, "System for simultaneous measurements of bilaterally symmetrical acupoints multifrequency impedances," *Med. Devices, Evidence Res.*, vol. 6, p. 203, Nov. 2013.
[27] G. Xu, H. Y. Yang, T. Y. Liu, M. Gao, and W. C. Tang, "Design and implementation of a method for temperature parameter collection inside acupoint," *Zhongguo Zhen Jiu = Chinese Acupuncture Moxibustion*, vol. 39, no. 8, pp. 901–906, 2019.
[28] L. Tang, Y. Li, H. Xie, Q. Shu, F. Yang, Y.-L. Liu, F. Liang, H. Wang, W. Huang, and G.-J. Zhang, "A sensitive acupuncture needle microsensor for real-time monitoring of nitric oxide in acupoints of rats," *Sci. Rep.*, vol. 7, no. 1, p. 6446, Jul. 2017.
[29] J. Chen, Q. Tu, S. Miao, Z. Zhou, and S. Hu, "Transcutaneous electrical acupoint stimulation for preventing postoperative nausea and vomiting after general anesthesia: A meta-analysis of randomized controlled trials," *Int. J. Surg.*, vol. 73, pp. 57–64, Jan. 2020.
[30] Z. Lu, Q. Wang, X. Sun, W. Zhang, S. Min, J. Zhang, W. Zhao, J. Jiang, Y. Wang, Y. Zhu, and L. Zheng, "Transcutaneous electrical acupoint stimulation before surgery reduces chronic pain after mastectomy: A randomized clinical trial," *J. Clin. Anesthesia*, vol. 74, Nov. 2021, Art. no. 110453.
[31] F. Qu, R. Li, W. Sun, G. Lin, R. Zhang, J. Yang, L. Tian, G.-G. Xing, H. Jiang, F. Gong, X.-Y. Liang, Y. Meng, J.-Y. Liu, L.-Y. Zhou, S.-Y. Wang, Y. Wu, Y.-J. He, J.-Y. Ye, S.-P. Han, and J.-S. Han, "Use of electroacupuncture and transcutaneous electrical acupoint stimulation in reproductive medicine: A group consensus," *J. Zhejiang Univ.-Sci. B*, vol. 18, no. 3, pp. 186–193, Mar. 2017.
[32] D. Wang, H. Shi, Z. Yang, W. Liu, L. Qi, C. Dong, G. Si, and Q. Guo, "Efficacy and safety of transcutaneous electrical acupoint stimulation for postoperative pain: A meta-analysis of randomized controlled trials," *Pain Res. Manag.*, vol. 2022, Apr. 2022, Art. no. 7570533.
[33] G. Litscher, "Modernization of traditional acupuncture using multimodal computer-based high-tech methods—Recent results of blue laser and teleacupuncture from the Medical University of Graz," *J. Acupuncture Meridian Stud.*, vol. 2, no. 3, pp. 202–209, 2009.
[34] S.-C. Chang, C.-C. Kuo, C.-H. Ni, C.-C. Tsai, S.-F. Yen, Y.-H. Chiu, A.-D. Qu, and C.-Y. Wang, "Emulated laser-acupuncture system," *Appl. Opt.*, vol. 53, no. 29, p. 170, 2014.
[35] G. Litscher, Z. Xie, L. Wang, and I. Gaischek, "Blue 405 nm laser light mediates heart rate—Investigations at the acupoint Neiguan (Pe. 6) in Chinese adults," *North Amer. J. Med. Sci.*, vol. 1, no. 5, p. 226, 2009.
[36] J. L. Wen, S. X. Li, Q. M. Wang, G. Xu, and M. Gao, "Design and development of a novel infrared mild moxibustion device," *Zhongguo Zhen Jiu = Chinese Acupuncture Moxibustion*, vol. 43, no. 1, pp. 13–109, 2023.
[37] S. M. Sator-Katzenschlager and A. Michalek-Sauberer, "P-Stim auricular electroacupuncture stimulation device for pain relief," *Exp. Rev. Med. Devices*, vol. 4, no. 1, pp. 23–32, Jan. 2007.
[38] K.-C. Lan and G. Litscher, "Robot-controlled acupuncture—An innovative step towards modernization of the ancient traditional medical treatment method," *Medicines*, vol. 6, no. 3, p. 87, Aug. 2019.
[39] T. Xu and Y. Xia, "Guidance for acupuncture robot with potentially utilizing medical robotic technologies," *Evidence-Based Complementary Alternative Med.*, vol. 2021, pp. 1–11, Mar. 2021.
[40] T. W. Chan, C. Zhang, W. H. Ip, and A. W. Choy, "A combined deep learning and anatomical inch measurement approach to robotic acupuncture points positioning," in *Proc. 43rd Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. (EMBC)*, Nov. 2021, pp. 2597–2600.
[41] K.-C. Lan, C.-Y. Lee, G.-S. Lee, T.-H. Tsai, Y.-C. Lee, and C.-Y. Wang, "An initial study on automated acupoint positioning for laser acupuncture," *Evidence-Based Complementary Alternative Med.*, vol. 2022, pp. 1–9, Aug. 2022.
[42] Q. Fang, R. Bedi, B. Ahmed, and I. Cosic, "Comparison of skin resistance between biological active points of left and right hands with various contact pressures," in *Proc. 26th Annu. Int. Conf. IEEE Eng. Med. Biol. Soc.*, Sep. 2004, pp. 2995–2998.
[43] C. S. Poon, T. T. C. Choy, and F. T. Koide, "A reliable method for locating electropermeable points on the skin surface," *Amer. J. Chin. Med.*, vol. 8, no. 3, pp. 283–289, Jan. 1980.
[44] M. Reichmanis, A. A. Marino, and R. O. Becker, "DC skin conductance variation at acupuncture loci," *Amer. J. Chin. Med.*, vol. 4, no. 1, pp. 69–72, 1976.
[45] S. Rezaei, A. Khorsand, and J. Jamali, "Characterisation of human skin impedance at acupuncture point Pc4 ximen and pericardium meridian using the four-electrode method," *Acupuncture Med.*, vol. 30, no. 2, pp. 127–131, Jun. 2012.
[46] J. Wei, X. Shen, and T. Wang, "The resistance of acupoint and its measurement," *J. Biomed. Eng.*, vol. 23, no. 3, pp. 509–511, 2006.
[47] D. Meng, Y. Mao, Q.-M. Song, C.-C. Yan, Q.-Y. Zhao, M. Yang, G. Xiang, and Y. Song, "Efficacy and safety of transcutaneous electrical acupoint stimulation (TEAS) for postoperative pain in laparoscopy: A systematic review and meta-analysis of randomized controlled trials," *Evidence-Based Complementary Alternative Med.*, vol. 2022, pp. 1–17, Jan. 2022.
[48] A. J. Vickers and K. Linde, "Acupuncture for chronic pain," *Jama*, vol. 311, no. 9, pp. 955–956, 2014.
[49] R. Zhang, L. Lao, K. Ren, and B. M. Berman, "Mechanisms of acupuncture-electroacupuncture on persistent pain," *Anesthesiology*, vol. 120, no. 2, pp. 482–503, Feb. 2014.
[50] Z.-T. Lv, L.-L. Shen, B. Zhu, Z.-Q. Zhang, C.-Y. Ma, G.-F. Huang, J. Yin, L.-L. Yu, S.-Y. Yu, M.-Q. Ding, J. Li, X.-C. Yuan, W. He, X.-H. Jing, and M. Li, "Effects of intensity of electroacupuncture on chronic pain in patients with knee osteoarthritis: A randomized controlled trial," *Arthritis Res. Therapy*, vol. 21, no. 1, pp. 1–10, Dec. 2019.
[51] W. Ya-Sheng and X. U. Ping, "Design of test circuits for human meridian dynamic resistance," *J. Transducer Technol.*, vol. 23, no. 10, pp. 45–47, Oct. 2004.
[52] X. U. Fei-Peng and G. Yi, "Reports on electroacupuncture device parameters and analysis of its measured output frequencies," *Shanghai J. Acupuncture Moxibustion*, vol. 35, no. 9, p. 4, 2016.

[53] A. Sarkova and M. Sarek, "EAV and gemmotherapy—Medicine for the next millennium? (technique as a means to link eastern and western medicine)," in *Proc. IEEE Eng. Med. Biol. 27th Annu. Conf.*, Jan. 2005, pp. 4943–4946.

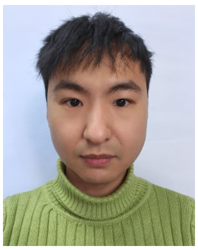
[54] K. Stähler van Amerongen, A. Kuhn, D. Surbek, and M. Nelle, "Ear acupuncture points in neonates from drug-dependent mothers: A prospective study," *Frontiers Pediatrics*, vol. 9, Jun. 2021, Art. no. 668248.

[55] K. M. Sancier, "The effect of qigong on therapeutic balancing measured by electroacupuncture according to Voll (EAV): A preliminary study," *Acupuncture Electro-Therapeutics Res.*, vol. 19, no. 2, pp. 119–127, Jan. 1994.

[56] Y.-N. Ma, "Analysis on resistance testing and technological research of acupoints," *Zhongguo Zhen Jiu = Chinese Acupuncture Moxibustion*, vol. 31, no. 12, pp. 1087–1091, 2011.

[57] Y. Xuming, Y. Yijun, X. Yong, W. Xuanzhong, W. Zheyu, N. Hongmei, Z. Ying, and X. Lingyu, "A precise and accurate acupoint location obtained on the face using consistency matrix pointwise fusion method," *J. Traditional Chin. Med.*, vol. 35, no. 1, pp. 110–116, Feb. 2015.

ZHENG YU received the Ph.D. degree in acupuncture and moxibustion from the Chengdu University of Traditional Chinese Medicine, Chengdu, China. From 2014 to 2020, she worked as an Acupuncturist at the Chengdu City Pidu District Hospital of Traditional Chinese Medicine. She is currently a Lecturer with the School of Intelligent Medicine, Chengdu University of Traditional Chinese Medicine. Her research interests include the development of intelligent equipment of TCM and the specificity of acupoint effects. She is a Council Member of the Sichuan Acupuncture and Moxibustion Society.



SHENGYAN ZHANG received the B.M. degree in traditional Chinese medicine from the Heilongjiang University of Traditional Chinese Medicine, Harbin, China. He is currently pursuing the master's degree in science of acupuncture and moxibustion with the Chengdu University of Traditional Chinese Medicine, Chengdu, China. His research interests include research on evidence-based medicine and acupuncture clinical efficacy evaluation and development of intelligent equipment of TCM.

LINSHUAI ZHANG received the Ph.D. degree in intelligent mechanical systems engineering from Kagawa University, Japan, and the Ph.D. degree in mechanical engineering from the Changchun University of Science and Technology, China. He is currently an Associate Professor with the School of Intelligent Medicine, Chengdu University of Traditional Chinese Medicine, Chengdu, China. He is also an overseas high-level overseas talent in Sichuan Province. His current research interests include medical robot systems for minimal invasive surgery, teleoperation systems, and intelligent mechanical system and sensing.

CHUANBIAO WEN received the M.D. degree in software engineering from the University of Electronic Science and Technology of China, Chengdu, China. He is currently a Professor with the School of Intelligent Medicine, Chengdu University of Traditional Chinese Medicine, Chengdu. He is the Director of the Sichuan Digital Engineering Technology Research Center of Traditional Chinese Medicine, and the Discipline Leader of Traditional Chinese Medicine Informatics of the State Administration of Traditional Chinese Medicine. His research interests include blockchain Chinese medicine traceability, medical big data, cloud health platform, and health wearable device research and development.

SHUGUANG YU received the B.M. degree in acupuncture and moxibustion from the Chengdu University of Traditional Chinese Medicine, Chengdu, China. He is currently a Professor with the Acupuncture and Tuina School, Chengdu University of Traditional Chinese Medicine. He is an Academic Leader in the National Key Discipline of Acupuncture and Moxibustion, and he has been recognized as a National Outstanding Scientific and Technological Worker. His research interests include the principle of moxibustion and the basis of acupuncture nerve rehabilitation.

JIAQI SUN received the B.M. degree in traditional Chinese medicine from the Hebei University of Traditional Chinese Medicine, Shijiazhuang, China. She is currently pursuing the master's degree in science of acupuncture and moxibustion with the Chengdu University of Traditional Chinese Medicine, Chengdu, China. Her research interests include evidence-based medicine and acupuncture clinical efficacy evaluation and development of intelligent equipment of TCM.

SUHENG DENG received the B.M. degree in traditional Chinese medicine from the Tianjin University of Traditional Chinese Medicine, Tianjin, China. She is currently pursuing the master's degree in science of acupuncture and moxibustionat with the Chengdu University of Traditional Chinese Medicine, Chengdu, China. She is also a Lecturer with the School of Intelligent Medicine, Chengdu University of Traditional Chinese Medicine. Her research interests include research on evidence-based medicine and acupuncture clinical efficacy evaluation and development of intelligent equipment of TCM.

HONGFU CI received the B.M. degree in traditional Chinese medicine from Binzhou Medical University, Yantai, China. He is currently pursuing the master's degree in science of acupuncture and moxibustion with the Chengdu University of Traditional Chinese Medicine, Chengdu, China. His research interests include evidence-based medicine and acupuncture clinical efficacy evaluation and development of intelligent equipment of TCM.

YANXIONG GAN received the Ph.D. degree in pharmaceutics from China Pharmaceutical University, Nanjing, China. He is currently a Lecturer with the School of Intelligent Medicine, Chengdu University of Traditional Chinese Medicine, Chengdu, China. His current research interest includes intelligent medical systems.