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Safe Experimentation Dynamics Algorithm for Identification of Cupping Suction Based on the Nonlinear Hammerstein Model

Kavindran Suresh [1], Mohd Riduwan Ghazali [2], Mohd Ashraf bin Ahmad [3]
[1, 2, 3] Faculty of Electrical and Electronics Engineering Technology, University Malaysia Pahang Al-Sultan Abdullah, Malaysia
Email: [1] kavinsuresh147@gmail.com, [2] riduwan@umpsa.edu.my, [3] mashraf@umpsa.edu.my

Abstract—**The use of cupping therapy for various health benefits has increased in popularity recently. Potential advantages of cupping therapy include pain reduction, increased circulation, relaxation, and skin health. The increased blood flow makes it easier to supply nutrients and oxygen to the tissues, promoting healing. Nevertheless, the effectiveness of this technique greatly depends on the negative pressure's ability to create the desired suction effect on the skin. This research paper suggests a method to detect the cupping suction model by employing the Hammerstein model and utilizing the Safe Experimentation Dynamics (SED) algorithm. The problem is that the cupping suction system experiences pressure leaks and is difficult to control. Although, stabilizing the suction pressure and developing an effective controller requires an accurate model. The research contribution lies in utilizing the SED algorithm to tune the parameters of the Hammerstein model specifically for the cupping suction system and figure out the real system with a continuous-time transfer function. The experimental data collected for cupping therapy exhibited nonlinearity attributed to the complex dynamics of the system, presenting challenges in developing a Hammerstein model. This work used a nonlinear model to study the cupping suction system. Input and output data were collected from the differential pressure sensor for 20 minutes, sampling every 0.1 seconds. The single-agent method SED has limited exploration capabilities for finding optimum value but excels in exploitation. To address this limitation, incorporating initial values leads to improved performance and a better match with the real experimental observations. Experimentation was conducted to find the best model parameters for the desired suction pressure. The therapy can be administered with greater precision and efficacy by accurately identifying the suction pressure. Overall, this research represents a promising development in cupping therapy. In particular, it has been demonstrated that the proposed nonlinear Hammerstein models improve accuracy by 84.34% through the tuning SED algorithm.**

Keywords—Cupping Suction; Identification; Nonlinear Model; Hammerstein Model; Safe Experimentation Dynamics.

I. INTRODUCTION

The cupping system began early in Traditional Chinese Medicine and the Middle East, but now it is a famous therapy in healthcare modalities [1], [2], [3]. Traditional Chinese medicine holds that illnesses occur when Qi, the vital life energy, becomes blocked. Cupping therapy is believed to help remove these blockages and restore the smooth flow of Qi, thereby improving overall well-being. In East Asia, cupping has become a popular alternative treatment for various health issues. The practice of cupping dates back over 5500 years in Egypt and has been documented in Arabic cultures since around 3500 BC in ancient Chinese records. The earliest accounts of cupping can be traced back to an ancient silk book [4], [5], [6]. The Hijama refers to the historical practice of utilizing cups to generate suction on the skin to promote relaxation, reduce inflammation, and relieve pain [7], [8]–[10]. Athletes usually use cupping therapy to ease muscle pain, but regular individuals can also use it for neck, shoulder, hypertension [11], back, and headache/migraine discomforts [12]–[14]. Moreover, cupping therapy is usually divided into two categories: wet and dry cupping [15]. Dry cupping refers to cupping that does not involve bloodletting. Wet cupping is a more extensive variation of the cupping practice which involves bloodletting after placing the cups on the body [16], [17], [18].

Additionally, skin tension will be one of the factors after deciding whether the cupping therapy, either wet or dry, is characterized as clean, medium, or hairy. The skin surface will be pulled inside the cup faster on a clean surface than on a hairy surface by negative pressure [19]. The blood vessels expand and redden the skin due to negative pressure inside the cup [6], [8], [20], [22], [25], [26], [27], [28], [29] and [30]. Even though cupping therapy influences the type of skin tension, high-pressure cupping increases blood flow to the measured area, causing vasodilation and sweating [1]. This condition will be the highest cause of blisters on the skin [20], [30]–[32], [33]. A recent study proposed the development of a cupping suction system that incorporates automatic control, simultaneous suction outputs, and alert mechanisms with a time display [34]. By employing fuzzy control as an intelligent controller, this system offers advantages such as reduced power consumption and improved control over skin engulfment [15], [34], [35]. The current automatic cupping system encounters issues with unstable control due to an inaccurate model. Therefore, maintaining consistent pressure control is essential, requiring a highly accurate model to regulate the cupping suction system based on identified parameters effectively.

An approach that has gained traction in studying the cupping suction system involves the development of an accurate mathematical model for it. This model primarily focuses on analyzing the input and output of the real continuous-time data obtained from the cupping suction experiment [36]. By utilizing input and output data measurements, data-driven system identification can derive accurate mathematical models of the underlying system, optimizing the system's performance [37]–[41].

Moreover, data-driven system identification can also help to identify potential risks and complications associated with cupping therapy, allowing more proactive and personalized approaches for better treatment [42]. Black box modelling is simple in a complicated, nonlinear plant [43], [44], [45]. Black box modelling has been effectively used in earlier studies to comprehend various systems, such as Polymer Electrolyte Membrane (PEM) fuel cells [46], Quadrotor dynamics [47], DC-DC converters [48], and School Payment Information Systems [49]. In black box modelling, the system's fundamental structures and first-principal equations are assumed to be unknown [50]. Building upon this prior application, black box modelling to analyze the relationship between motor speed and suction power. The plant's behavior is then mathematically represented using the Hammerstein model, which combines a linear dynamic block for the system dynamics with a static nonlinear block for the input-output relationship [51]–[54]. The Hammerstein model allows linearizing the nonlinear plant, making it especially appropriate for the cupping suction system. On the other hand, the nonlinear function captures the input-output behavior of a system that cannot be adequately modeled using linear differential equations [55]–[57]. The transfer function represents the linear dynamics system, illustrating the connection between the system's input and output by utilizing linear differential equations, such as polynomial, exponential, and hyperbolic functions.

Data-driven required data-driven tools to find the optimal parameter of the nonlinear mathematical model. Data-driven tools have various optimization methods, such as the multi-agent-based optimization method [58] and single-agent-based optimization. Likewise, in multi-agent-based optimization, a Genetic Algorithm has been utilized in a wellhead back pressure control system [59], Particle Swarm Optimization has been used in quadrotor identification [60], and Sine-cosine algorithm-based optimization has been utilized for automatic optimization voltage regulator system [61], [62]. Additionally, the sine cosine algorithm has been used to model cupping suction systems, where models for cupping suction systems were created using the sine cosine method, allowing for a thorough knowledge of their performance and behavior [63]. This multi-agent has certain advantages in exploration in finding the optimal parameters. However, multi-agent-based consumes more computation time than a single agent [64]–[66].

On the other hand, the Safe Experimentation Dynamics (SED) algorithm is one of the most popular single-based solution optimization methods to give steady convergence and accurate ideals. SED is a memory-based optimization since it retains parameter values whenever the optimal design parameter value is produced for each iteration. Particularly, the SED optimization method has been applied in control systems such as Neuroendocrine [67], Liquid Slosh [68], DC/DC Buck-Boost Converter-Inverter-DC Motor [65], Double Pendulum-Type Overhead Crane System [69], Pantograph-Catenary system [70], Flexible Joint Robot [66] and DC Motor [65]. The SED is excellent at exploitation but has limited exploring ability to find the best solution. Setting the initial parameters accurately can improve its ability to exploit the best solution effectively [65], [67], [70], [71].

The research paper introduces the nonlinear Hammerstein model of the cupping suction system based on the SED (Safe Experimentation Dynamics) algorithm. The research contribution

- Utilizes SED algorithm-based data-driven system identification to tune parameters of the Hammerstein model, specifically for the cupping suction system.
- Determines the data driven nonlinear cupping systems in hairy situations and minimizes the objective function.

The research paper has a clear organizational framework. The cupping suction experiment is described in Section II. Moving on, Section III formulates the data-driven system identification problem, focusing on tuning the Hammerstein model for the cupping suction system, and presents details about the implementation of safe experimentation dynamics. The simulation results are shown in Section IV, followed by an extensive discussion. Finally, Section V brings the paper to a close by summarizing the major findings and highlighting their implications.

II. CUPPING SUCTION EXPERIMENT

This research involves a systematic approach to developing a cupping suction apparatus, as depicted in Fig. 1. First, the hardware and system structure are developed. The cupping suction device is then used to collect thorough input and output real-time data. The SED technique is used to build the mathematical model of the cupping system utilising this data. The process is then subjected to detailed analysis to understand the model's properties and performance.

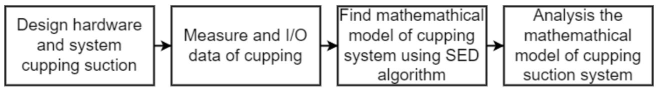

Fig. 1. Block diagram of the system

Furthermore, Fig. 2 includes strates the sequential steps in the process, which include reviewing current systems, design, data collecting, application of the Hammerstein model, experiment-based parameter optimization, and thorough result evaluation. If the results are as expected, the procedure is complete; if not, iterative model refinement is carried out to improve performance and efficacy. The block diagram and the flowchart show how the cupping suction system has been developed, modelled and how it could be optimized.

To establish the experimental pressure sensor setup [72]–[74], a differential pressure sensor (MPX5100DP) was connected to both the controller board and pump [75], [76], [77], as depicted in Fig. 3 (research diagram) and Fig. 4 (hardware wiring diagram). The controller software set up the pins for the pressure sensor and made it possible to send data from the pressure sensor to the serial monitor through serial communication. A 12V adaptor ensured sufficient current for the system, while the pump's connection to digital ports optimized suction power. An electrical cupping suction system was successfully created due to these setups, Fig. 5.

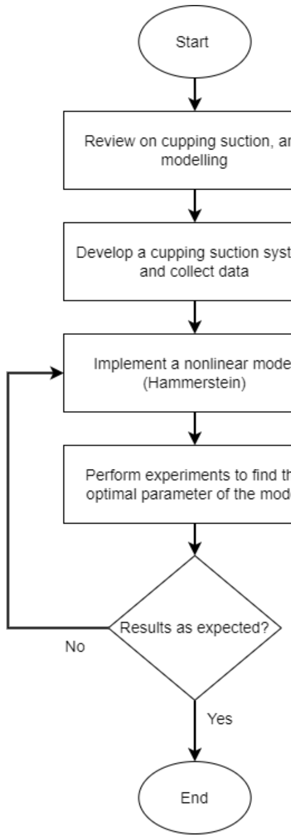

Fig. 2. Flowchart of the system

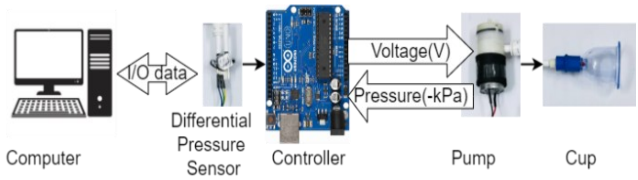

Fig. 3. Research diagram of data collection

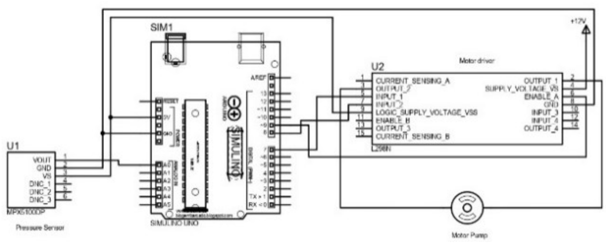

Fig. 4. Schematic diagram of the cupping suction system

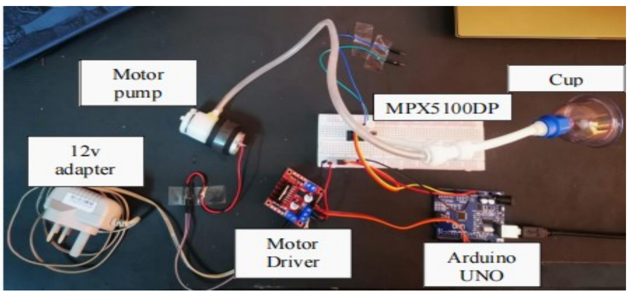

Fig. 5. Cupping Suction Experiment rig

During the cupping experiment conducted on a hairy surface of the human body to identify the model cupping suction shown in Fig. 6, certain challenges emerged due to pressure leakage and instability at low suction levels. To achieve the desired effects, hair removal was necessary. Addressing this, a modelling approach was devised using data from individuals with hairy skin. The pressure data in Fig. 7 was gathered within a specified pressure level range of 0 kPa to -60 kPa [28], [35], [78], [79], [80], in accordance with the current practice, which uses three levels of suction: light, medium, and high. The data collection process resulted in 12,000 data points gathered over a duration of 20 minutes, with a sampling rate of ten samples per second. The suction speed was randomly changed every 10 seconds to introduce complexity and variability in the experiment. This variation in suction speed significantly impacts the development of the cupping suction model. For greater accuracy in representing the intricate behavior of the cupping suction system, the model can be improved by integrating a wide range of suction levels. We can develop a mathematical model of the cupping suction system by utilizing the collected pressure data. To optimize its performance, data-driven approaches are employed, such as creating the Hammerstein model based on SED. Details about this process are provided in the next section.

Fig. 6. Experiment on hairy skin

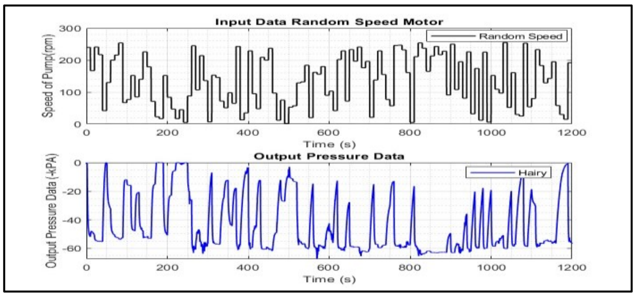

Fig. 7. Input-Output of cupping suction

III. Identification of Cupping Suction using Hammerstein-Based Safe Experimentation Dynamics

The cupping suction system is an example of a nonlinear system that the Hammerstein model is frequently used to describe. This section presents the suggested safe experimentation dynamics (SED) based on the Hammerstein model for identifying the cupping suction in Section 2.

The SED algorithm employs a single-agent optimization technique in its data-driven system identification and control approach. This approach produces stable parameter values that may be used during the tuning process and can detect the system's parameters more quickly than multi-agent-based approaches. Firstly, a problem formulation based on the Hammerstein model is used to identify the cupping suction. The transfer function $G(s)$ is a general equation for the transfer function, followed by the Hammerstein model function $w(t)$. The linear and Hammerstein model subsystems are given equation (1) and equation (2), respectively. Here, a and b are constants, and S is a complex variable.

$$G(s) = \frac{A(s)}{B(s)} = \frac{a_m S^m + a_{m-1} S^{m-1} + \cdots a_1 S + a_0}{b_m S^m + b_{m-1} S^{m-1} + \cdots b_1 S + b_0} \quad (1)$$

$$w(t) = c_m u^m + c_{m-1} u^{m-1} + c_{m-2} u^{m-2} + \cdots c_1 u + c_0 \quad (2)$$

In the real plant, the input is represented as $u(t)$, and the output is denoted by $y(t)$. The identified model, on the other hand, is denoted as $\tilde{y}(t)$. Therefore, the expression for the identified output can be written as (3).

$$\tilde{y}(t) = G(s) w(u(t)) \quad (3)$$

The assumed order of the polynomial, denoted as $A(s)$ and $B(s)$, is considered known. Once the experiment is established, a sampling time, denoted as t_s, is defined for collecting the actual input and output data from the experiment at specific time intervals $(t = 0, t_s, 2t_{s,} 3t_{s,} 4t_s, 5t_s, \ldots, Nt_s)$. Subsequently, a cupping suction model is identified by employing the objective function outlined in equation (4) in the following manner:

$$E(G,w) = \frac{1}{N} \sum_{0}^{N} (y(Nt_s) - \tilde{y}(Nt_s))^2 \quad (4)$$

It is important to note that, in this model, the objective function is computed using equation (4), considering the mean square errors. This calculation is performed prior to further discussion on given problems.

Problem 1. Given the real experiment data of input $u(t)$ and output $y(t)$, as depicted in Fig. 7, the objective is to determine the nonlinear function $w(\mathrm{u}(t))$ and transfer function $G(s)$ in way that minimizes the objective function described in equation (4). The block diagram of the Hammerstein model is illustrated in Fig. 8 by using data driven system identification in MATLAB.

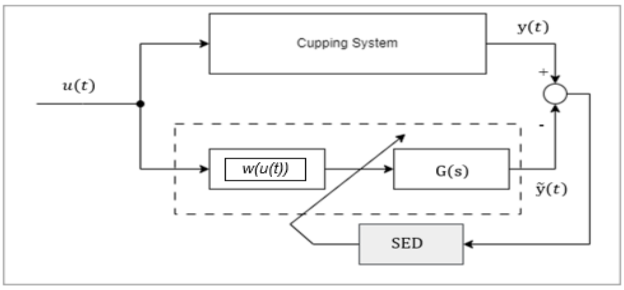

Fig. 8. Block diagram of Hammerstein model-based SED algorithm

Furthermore, it demonstrated applying the Safe Experimentation Dynamics (SED) approach to address **Problem 1**. To simplify the representation, the design parameter can be denoted as $x = [a_0\ a_1\ a_{m-1}\ b_0\ b_1\ b_{m-1}\ c_0 \ldots\ c_m]$, where the elements of the design parameter correspond to the coefficients of both the nonlinear function and the transfer function in the continuous-time Hammerstein model. Consider an 8th-order continuous-time transfer function and a polynomial function in equation (5) and equation (6) for linear and Hammerstein model subsystems, respectively, based on several preliminary experiments, and this is the structure of the Hammerstein model [81], [82]. The Hammerstein model subsystem created should be responsible for locating the negative pressure in the cupping suction model.

$$G(s) = \frac{A(s)}{B(s)} = \frac{s^5 + a_4 s^4 + a_3 s^3 + a_2 s^2 + a_1 s + a_0}{s^8 + b_7 s^7 + b_6 s^6 + b_5 s^5 + b_4 s^4 + b_3 s^3 + b_2 s^2 + b_1 s + b_0} \quad (5)$$

$$w(u(t)) = -c_1 u(t) + c_2 u(t)^2 + c_3 u(t)^3 + c_4 u(t)^4 \quad (6)$$

The challenge of the optimization problem is considered in equation (7).

$$\min_{p \in R^n} f(\boldsymbol{p}) \quad (7)$$

In this context, the objective function is denoted as $f: R^n \to R$, where $\boldsymbol{p} \in R^n$ represents the design parameter. The SED algorithm is utilised to iteratively update the design parameter to obtain the optimal solution $\boldsymbol{p}^* \in R^n$ for the optimisation problem outlined in equation (7).

The update law for the SED algorithm can be expressed as (8).

$$p_i(k+1) = h(\bar{p}_i - K_g r_2) \quad (8)$$

In this context, the iteration process is denoted by $k = 0,1, \ldots.. k_{max}$, where k_{max} represents the maximum number of iterations. Here, $p_i \in R$ signifies the i^{th} element of the design parameter $\boldsymbol{p} \in R^n$. Similarly, $\bar{p}_i \in R$ represents the i^{th} element of $\bar{\boldsymbol{p}} \in R^n$ and $\bar{\boldsymbol{p}}$ which serves as a storage variable to hold the current best value of the design parameters. Additionally, K_g is a scalar value that determines the interval size for determining the random steps taken on $p_i \in R$, while $r_2 \in R$ denotes the value of a randomly generated number.

$$h(\bar{p}_i - K_g r_2) = \begin{cases} p_{max}, & \bar{p}_i - K_g r_2 > p_{max}, \\ p_{min}, & \bar{p}_i - K_g r_2 < p_{min}, \end{cases} \quad (9)$$

The step-by-step procedures of the SED algorithm are determined based on the pre-defined maximum value, p_{max} and minimum value, p_{min}, of the design parameters. These procedures can be summarised as follows:

Step 1: Begin by determining the values for pre-defined maximum and minimum design parameters, p_{max} and p_{min}, respectively. Additionally, establish the values for K_g, and E. Initialize $k = 0$, and set initial conditions for the design parameters $\boldsymbol{p}(0)$, with the objective function being $f(\boldsymbol{p}(0))$. By default, assign $\bar{\boldsymbol{p}} = \boldsymbol{p}(0)$ and $\bar{f} = f(\boldsymbol{p}(0))$.

Note that E represents a scalar determining the probability of employing a new random setting for $\boldsymbol{p}$. The variable $\bar{f}$ is used to store the current best value of the objective function.

Step 2: Check if the value of $f(\boldsymbol{p}(k))$ is less than $\bar{f}$. If this condition is met, update $\bar{\boldsymbol{p}}$ as $\boldsymbol{p}(k)$, and $\bar{f}$ as $f(\boldsymbol{p}(k))$. Otherwise, please proceed to step 3.

Step 3: Generate a random number r_1. If r_1 is less than E, generate a second random number r_2. Utilized the update law defined in equation (8) to determine the value for $p_i(k+1)$. Otherwise, assign $p_i(k+1) = \bar{p}_i$.

Note that, $r_1 \in R$ is a randomly selected number from a uniform distribution ranging between 0 and 1, while r_2 falls within the range of p_{min} and p_{max} .

Step 4: Compute the objective function $f(p_i(k+1))$.

Step 5: Verify if the pre-determined termination condition is met. If satisfied, the algorithm concludes, and the solution is given as $p^* := arg \min_{\boldsymbol{p} \in \{\boldsymbol{p}(0), \boldsymbol{p}(\mathbf{1}), \ldots\ldots \boldsymbol{p}(k+1)\}} f(\boldsymbol{p})$. Otherwise, increment k by 1 and proceed to step 2. The termination condition is established based on the specified maximum number of iterations, k_{max}.

IV. RESULTS AND DISCUSSION

In this section, the effectiveness of the SED-based method in identifying the cupping suction mechanism is demonstrated using the Hammerstein model. The Cupping Suction Experiment serves as the basis for this demonstration. By having a clear model, the practitioners can customize the treatments for individual patients, leading to better outcomes. The input response, denoted as $u(t)$, presented in Fig. 7, is applied to the cupping suction plant. Correspondingly, the resulting output response, referred to as $y(t)$, is recorded and displayed in Fig. 7. Hence, the parameters where each element of $\boldsymbol{LS}$ denoted as $\boldsymbol{LS_i} = \boldsymbol{10^{P_i}(i = 1, 2, \ldots 17)}$ and the optimal parameters are denoted as $\boldsymbol{LS_{opt}} = [\boldsymbol{10^{P_{1opt}}}, \boldsymbol{10^{P_{2opt}}}, \ldots \boldsymbol{10^{P_{17opt}}}]$. It is important to note that the input and output data were sampled at time intervals. $t_s = 0.1s$, encompassing a total of $N = 12000$ samples. Other than that, the 8th-order transfer function was selected as mentioned in equation (1) for $G(s)$. The choice of the 8th-order transfer function for the cupping suction experiment is based on several factors, including the complexity of the system and the desired level of accuracy in the model. Generally, a higher-order transfer function can better represent the system's behavior more accurately than a lower-order function. However, higher-order functions can be more complex and require more parameters to be identified, which can be more difficult to work with. In the cupping suction system, it has been determined that an 8th-order transfer function was necessary to capture the system's dynamics accurately.

Subsequently, the SED algorithm was employed to fine-tune the design parameters using a pre-determined set of initial values. The SED coefficients were denoted as $p_{min} = -25$, $p_{max} = 25, E = 0.66$ and $K_g = 0.022$. Here we chose the maximum iterations $k_{max} = 50000$. The response of the objective function is depicted in Fig. 9, showcasing a significant improvement of 81.34 % with a resulting value of $E(G, w) = 72.3593$, thereby yielding the best parameters. The optimization process reached its optimal point iteration of 1500 out of 5000, after which the objective function values remained consistent. This convergence behavior indicates that the achieved results are reliable and satisfactory. The convergence curve response shows how the identified output gradually converges towards the actual output of the cupping suction system. The experiment was conducted to determine the best model, the first experiment without the Hammerstein model (real output) and the second experiment compared with the Hammerstein model (estimated output). The findings indicate that the method based on the SED algorithm successfully minimizes the initial objective function $E(G, w) = 120$ to 72.3593. This demonstrated in Fig. 9 and Fig. 10, where the output response $y(t)$ generated by Hammerstein model closely aligns with the actual output $\tilde{y}(t)$ after applying the SED algorithm. The dot-grey line represents the actual output, while the thick blue line illustrates the Hammerstein model output, fine-tuned using the SED algorithm. This significant association supports the model's ability to accurately represent the behavior of the cupping suction system in the actual world.

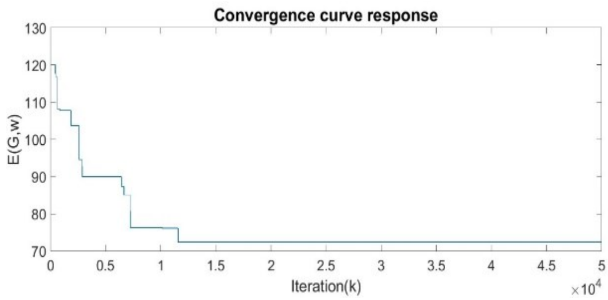

Fig. 9. Convergence curve response

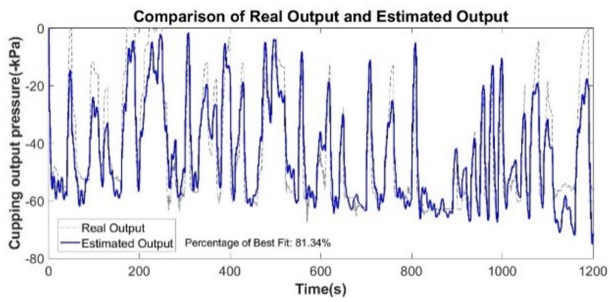

Fig. 10. Response of the identified output and real output

The Hammerstein model function feature was observed in the real experimental setup based on the input-output response. The data revealed the presence of negative pressure leakage and the fluctuation of the values in the graph. Negative pressure leakage is the loss of suction pressure from the cupping system due to air leakage and improper suction on a hairy surface. This happened when the low voltage was injected into the cupping suction, and the drastic drop in output pressure can be seen in Fig. 7. The suction force cannot maintain a constant level due to leakage. The results indicated that the applied Hammerstein model-based polynomial function is more efficient than without the Hammerstein model, which is the real output due to the Hammerstein model cupping suction system (refer to Table I). Additionally, accurate modelling opens possibilities for developing new technologies and integrating cupping therapy with other medical practices, which can bring about advancements in healthcare.

TABLE I. DESIGN PARAMETER OF CUPPING SUCTION

LS	Coefficients	$p(0)$	LS	p_{opt}	LS_{opt}
LS_1	a_4	0.78	6.03	0.97	9.33
LS_2	a_3	-20	1×10^{-20}	-19.79	1.62×10^{-20}
LS_3	a_2	0.27	1.86	0.71	5.13
LS_4	a_1	-4.69	2.04×10^{-5}	-3.87	1.35×10^{-4}
LS_5	a_0	-5.80	1.58×10^{-6}	-5.39	4.07×10^{-6}
LS_6	b_7	1.12	13.18	1.51	32.36
LS_7	b_6	1.60	39.81	1.67	46.77
LS_8	b_5	2.6	398.10	2.43	269.15
LS_9	b_4	2.19	154.88	2.13	134.90
LS_{10}	b_3	2.16	144.54	2.13	134.90
LS_{11}	b_2	1.55	35.48	1.71	51.29
LS_{12}	b_1	-2.28	5.24×10^{-3}	-2.43	3.72×10^{-3}
LS_{13}	b_0	-5.1	7.94×10^{-6}	-4.97	1.07×10^{-5}
LS_{14}	c_1	0.74	5.50	0.59	3.89
LS_{15}	c_2	-15.95	1.12×10^{-16}	-16.63	2.34×10^{-17}
LS_{16}	c_3	-19.6	2.51×10^{-20}	-19.31	4.9×10^{-20}
LS_{17}	c_4	-8.03	9.33×10^{-9}	-6.92	1.20×10^{-7}

V. CONCLUSION

This study used a methodology for identifying cupping suction, which involved using the SED algorithm in conjunction with a continuous-time Hammerstein model. The methodology comprised processes and elements, including parameter adjustment using the SED algorithm and the Hammerstein model. Significant gains made in parameter determination and model identification over previous methods- Sine Cosine Algorithm showed the proposed methodology to have strong potential. The precision and efficiency of the methodology in precisely recording the behavior of cupping suction, for instance, were demonstrated by instances from the findings section. Cupping suction presents difficulties in output prediction due to its inherent problem in precise forecasting. The proposed Hammerstein model handled this issue effectively by reflecting the complicated behavior of cupping suction.

Furthermore, the SED tuning method accurately and effectively predicted model parameters. It reduced tuning time and the objective function, suggesting its efficiency in optimizing the model's fit to real data. To provide a balanced perspective, explaining any limits or decisions connected with the SED tuning process is vital. When comparing the estimated output to the true output of a 20-minute cupping suction sample, the best fit attained was 81.34%. This high level of fit indicates the suggested approach's correctness and dependability in identifying the behavior of cupping suction. During cupping therapy, unstable pressure on hairy surfaces presented difficulties for the research that necessitated careful monitoring and aftercare. Additionally, the SED tuning method had issues with local optimal, which required adjusting the initial starting point to find different optimal solutions. Furthermore, the findings reveal practical implications for the suggested methodology in cupping suction identification. It has real-world applications and sectors where correct modelling of cupping suction is critical.

Future research could investigate specific sectors or domains where the proposed method could be used, such as healthcare, sports medicine, or rehabilitation. Furthermore, improving the methodology's implementation could entail correcting any discovered shortcomings, integrating additional variables, or improving computing performance. These techniques would enhance the understanding and implementation of cupping suction modelling in various scenarios.

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