ARTISTS' ARTICLE

Cursive Calligraphy in 3D and Bio-Ink

REM RUNGU LIN, YOU ZHOU, AND **KANG ZHANG**

ABSTRACT

This paper presents a generative approach to creating dynamic 3D cursive calligraphy by integrating motion and bio-data captured by EEG and EMG sensors with particle systems driven by vector fields. The artwork created through this method metaphorically and visually represents a calligrapher's energy, inspired by the traditional concept of *qi*. The authors use the term *bio-ink* to describe the visualization technique of this digital sculpture, which uses bio-data as parameters to control the flow and dynamism of the particles. Utilizing Unreal Engine 5, the authors create a dynamic 3D artwork that inspires further investigation into the therapeutic benefits of calligraphy, highlights the potential use of biofeedback in skill development, and paves the way for combining traditional arts with artists' life-data.

Digital art has increasingly been used to explore the possibilities of integrating traditional art forms with science and emerging technologies. Chinese calligraphy, a highly respected art form, is an area where such technological exploration has been pursued [1,2]. One essential aspect of Chinese calligraphy is the concept of qi, which can be described as the vital energy or spirit that flows through brushstrokes, reflecting the artist's creativity, emotions, and inner state [3].

In English, *qi* translates to concepts such as "air," "breath," "ether," and "material force" [4]. The word "force" particularly underscores qi's dynamic aspect, which resonates with the fundamental nature of calligraphy in the Chinese context [5].

The philosophy of qi in Chinese culture encompasses several core ideas. Qi is seen as a foundational life force, a primary energy (*yuan qi*) that connects all things, and a flow that balances the dual dynamics of *yin* and *yang*. Qi also refers to the vital essence (*jing*), energy (qi), and spirit (*shen*) found in everything from the environment to human beings. It is believed to be both the source and sustenance of life, with a person's vitality and creativity linked to its abundance [6]. This concept has deeply influenced calligraphy, informing the art's approach to life, unity, balance, the cultivation of vitality, and inherent character.

The act of creation in calligraphy can be viewed as a transformation or manifestation of qi. This vital energy flows from the calligrapher's mental and emotional state, through their physical movement, and is finally expressed into strokes and ink [7]. This is best demonstrated in cursive script, which seeks to convey the essence of the words while overlooking the intricacies of their form.

While qi in calligraphy has long been an elusive subject, this project approaches it as a source of inspiration rather than a definitive translation into digital form. To bridge the gap between the intangible qualities of qi and the data from biometrics and motion capture, we introduce the term *bio-ink* to denote a metaphorical concept, representing the digital visual medium that carries the biometric narrative of the calligrapher.

Traditional calligraphy's essence lies in its two-dimensional representations, which restrict the depth of engagement and appreciation of the work. Furthermore, the abstract nature of qi has been an ongoing challenge in visually representing the artist's internal creative process.

This paper introduces a generative approach to creating dynamic 3D cursive calligraphy by integrating motion and bio-data captured by electroencephalogram (EEG) and electromyography (EMG) devices with a particle system driven by a vector field. The result is a 3D dynamic artwork that offers new forms of appreciation of calligraphy beyond the traditional 2D limitations, and a metaphorical interpretation of qi.

The main contributions of this paper include (1) a systematic approach to generating cursive calligraphy that integrates the calligrapher's bio-data, transforming the embodiment of the artist's creativity, emotions, and inner state into an art

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form that can be tangibly perceived, and (2) the foundation and framework for future applications in therapeutic interventions or educational systems that can utilize biofeedback in artistic expression or skill development for calligraphy.

RELATED WORK

The artistic representation of calligraphy has long captivated scholars and practitioners, exploring various aspects such as stroke movement, ink visualization, and, more recently, bio-data integration. This section provides an overview of the existing literature relevant to our study, emphasizing the key contributions and limitations of previous research.

Stroke Movement

The artistry in calligraphy primarily lies in the aesthetics of stroke movement, which serve as a fundamental conduit for transmitting the calligrapher's artistic expression and emotional state [8]. Prior research has examined the brush's trajectory [9], width [10], and velocity [11], as well as geometric descriptions using parametric cones, ellipses [12], and Bézier curves [13]. These studies provide insights into the unique attributes of brush movements and how they relate to calligraphic aesthetics. However, none of them considered integrating the embodiment of the artist's bio-data as a new dimension of the aesthetics of stroke movement.

Ink Simulation

Beyond stroke movement, the dynamic representation of calligraphy is also dependent on the flow of ink. Progress in this area evolves from 2D to 3D, from static to dynamic simulations. Early efforts include Steve Strassmann's ink-laying process with a bristle brush on paper [14] and physically based methods to replicate ink dispersion on rice paper [15]. Other researchers have employed simple cellular automation to imitate ink spreading, crafted ink diffusion models [16], or applied modified LBE algorithms for ink dispersion [17], although these largely focus on static ink. Dynamic ink simulation is a more recent innovation, characterized by the use of 2D vector fields for fluid simulation [18], real-time grid-particle methods [19], and creative solutions like Tilt Brush that leverage generative strokes and animated shaders in 3D space [20]. Techniques involving 3D Particle systems [21] have further refined the simulation of fluid stroke movements, achieving visually appealing dynamics. Yet, despite these advancements, there remains a gap for innovation to use bio-data from EMG to effect the ink simulation during the writing process.

Bio-Data Integration

Integrating bio-data in artistic representations emerged in the 1960s [22] but continues to gain attention from artists. With ever-evolving advancements in technology and data analysis, researchers have begun to explore the potential of bio-data in a new light. Numerous studies have demonstrated the profound impact these data can have in augmenting the artistic experience and fostering a deeper understanding of the creative process. NeuroKnitting utilizes EEG data to knit artifacts, translating thought into tangible fabric [23]. In another exploration, biofeedback painting employs participants' heart activity as a medium, painting the rhythms of life into visual forms [24]. The Ars Electronica Futurelab's *Life Ink* project further expands these horizons, using ink-like effects to visualize creativity in real time [25]. While this existing research uses various artistic contexts, calligraphy's qi as a profound concept that emphasizes the emotional and inner state, and the intersection of bio-data and calligraphy visualization, remain unexplored.

Transition from 2D to 3D Representations

Progression from 2D to 3D representations is a subject of interest across various artistic domains. Tara Chittenden's exploration of the virtual reality (VR) painting app Tilt Brush discusses the opportunity these technologies present for rethinking traditional painting structures by allowing the creation of 3D imagery and an embodied relationship of the painter to painting [26]. Similarly, Sandra Blazheva has acknowledged the transformative impact of digital technologies, including Tilt Brush, on painting by eliminating the conventional canvas and instead offering a three-dimensional, virtual world for artists to express their imagination [27]. Alessandro Antonietti and Manuela Cantoia also highlight how VR could prompt a meta-perspective in users, encouraging abstract conceptualization and imaginative elaboration [28]. This advancement liberates artists from conventional restrictions, opening avenues for audiences to experience art in unprecedented ways.

Our methodology seeks to bridge the aforementioned research gaps by visually representing qi integrated with the calligrapher's movements. This synthesis integrates the trajectory, width, and velocity of stroke movement from motion capture, 3D particle system, and vector field for ink visualization with the incorporation of bio-data captured by EEG and EMG. The exploration could inspire further research in the artistic and scientific understanding of calligraphy, shedding light on the creative and emotional aspects of this ancient art form.

CONCEPTUAL FRAMEWORK

The integration of biofeedback in art creation presents a paradigm shift in how we understand and engage with the artistic process. This aligns with Marshall McLuhan's well-known assertion that "the medium is the extension of man," where the human body becomes a dynamic entity that can be extended through technology [29]. This extension is not limited to physical forms but embraces one's internal awareness, which McLuhan and, later, Jess Rowland argue can be considered a form of media [30]. Recent breakthroughs in neurotechnology, as mentioned by Rowland, further illustrate how one's inner perceptual states, or inner media, can be decoded and externalized [31]. By bridging mind, body, and machine, this concept seeks to unlock new frontiers in creativity, interactivity, and personalization, reflecting an emerging convergence between traditional artistic practices and new possibilities provided by technology.

Traditional Art Creation Loop

To elucidate neurofeedback's role in art creation, it is essential to understand the traditional artistic process from a computational logic perspective. This dynamic loop fosters an interactive relationship between artist and artwork, iteratively reshaping both. Guided by interconnected stages (Fig. 1), this loop consists of:

- **Artistic Knowledge (K):** artist's understanding of art theory, aesthetics, culture, and techniques
- **Artistic Exploration (E):** decisions and movements made by the artist during the creation process
- **Parameter (P):** parameters, such as trajectory, width, and velocity, that define the properties of the artwork
- **Artwork (A):** the evolving or final piece of art, reflecting the artist's intent and execution
- **Cognitive Capability (C):** artist's ability to interpret artistic elements
- **Five Senses (FS):** visual, acoustic, tactile, olfactory, and gustatory experiences

Integration of Neurofeedback

Our research builds upon this traditional loop, introducing a neurofeedback mechanism that intertwines the artist's cognitive functions and emotional states into the artwork's fabric. This approach functions through the following stages (Fig. 2):

- **Data Capture:** Biosensors record real-time cognitive and emotional data, defining the **Cognitive Capability (C)**.
- **Processing and Integration:** The information is analyzed and seamlessly channeled into the creative process, infusing a previously hidden layer of the artist's emotional or mental state into the **Artwork (A)**.
- **Introspection:** C-P-A-C forms a neurofeedback loop that unveils the artist's inner landscape, resonating with the artwork and forming an intimate connection [32].
- **Embodied Cognition:** Echoing the philosophy of embodied cognition, the neurofeedback loop binds the artist's mind and body with the artistic manifestation, creating a continuum where thoughts, emotions, and physical sensations interplay in an unceasing harmony [33].

In summary, this framework offers a new interpretation of artistic exploration where the artist's inner state as a medium becomes intricately woven with the artwork. It redefines the boundaries of artistic expression and adds a tangible and insightful dimension to the artist's inner world, enriching both the creation and appreciation of art.

METHODOLOGY

The creation of dynamic 3D cursive calligraphy represented by bio-ink requires a multifaceted approach. We have devised a comprehensive methodology that unites the aesthetics of traditional calligraphy with state-of-the-art technologies, providing a visual experience that transcends the limitations of conventional 2D art forms.

Our methodology rests upon three interconnected pillars: stroke movement, the integration of bio-data, and ink visualization (Fig. 3). Based on the conceptual framework, these three components interweave to create a vivid and immersive portrayal of the calligrapher's artistic expression.

Stroke Movement

The aesthetics of stroke movement in calligraphy play a vital role in conveying the artistic expression and emotions of the calligrapher [34]. Referring to the art creation loop in Fig. 2, these movements are deeply rooted in the calligrapher's artistic knowledge (K), encompassing his or her understanding of aesthetics, culture, and technique. This knowledge (K) drives the artistic exploration (E), which in calligraphy is the motion and rhythm of the brush.

Our approach transforms brush movements, captured by a motion capture system, into quantifiable data as neurofeedback. We map the brush's spatial trajectory, a representation of the calligrapher's parameter (P) choices, into a 3D vector field. This vector field captures not only the spatial path but also the stroke width and temporal aspects of brush movement.

The 3D vector field represents the velocity generated at each position in the artwork. The falloff curve $f(d)=e^{\alpha d}$ modulates this velocity based on proximity to the brush's path. As the brush moves vertically, it manipulates another parameter (P)—the width of the stroke. A higher vertical

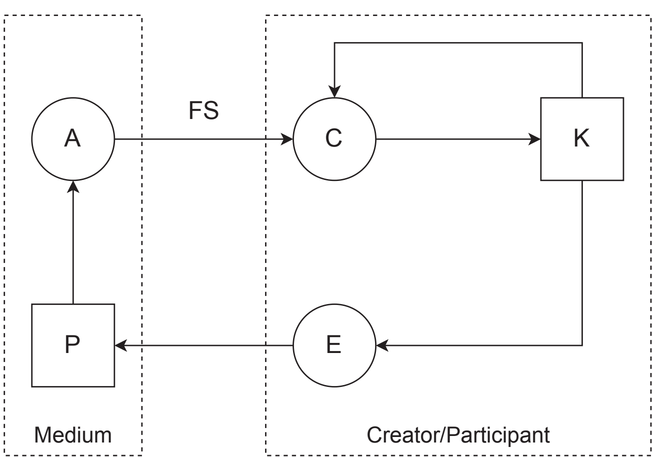

Fig. 1. Art creation loop. (© Rem RunGu Lin)

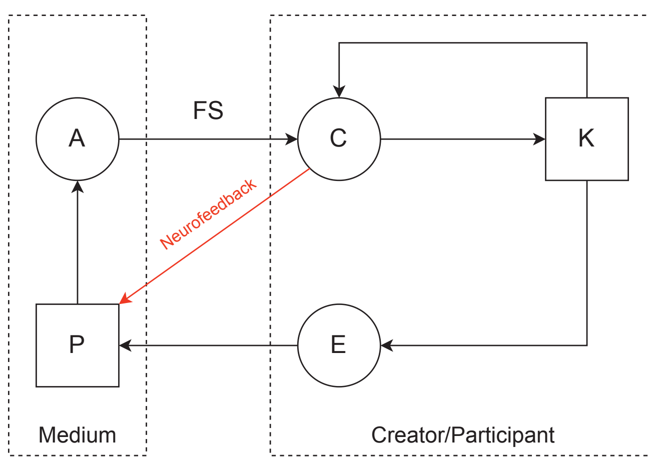

Fig. 2. Art creation loop integrated with neurofeedback loop. (© Rem RunGu Lin)

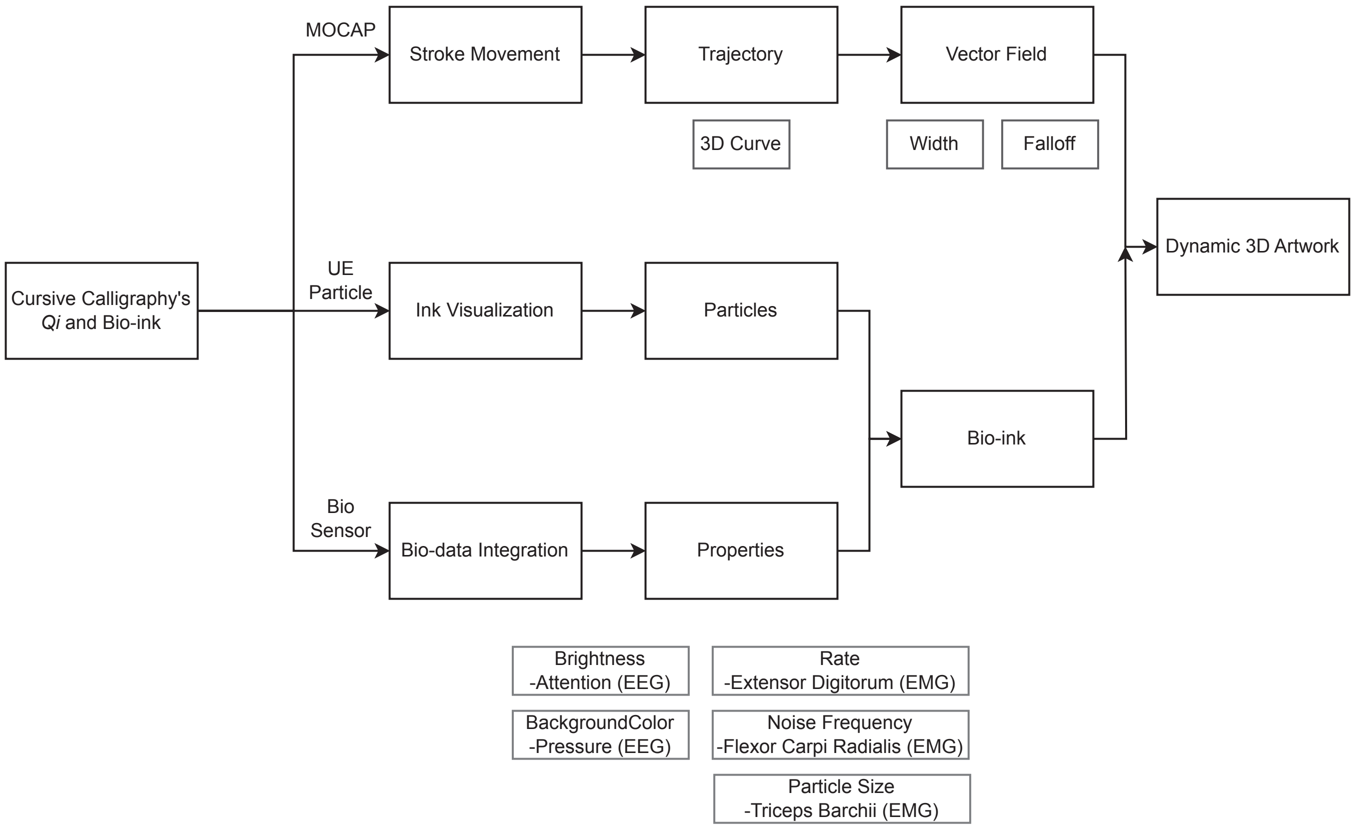

Fig. 3. The systematic approach to generating cursive calligraphy's *qi*. (© Rem RunGu Lin)

position is translated to a wider stroke, resonating with the traditional techniques of calligraphy.

To create this representation, we populate a matrix of zero vectors around the trajectory, guided by the falloff curve. For each point P in the 3D space, the vector field V(P) is calculated as follows:

```
VectorField(Trajectory trajectory, double alpha,
    vector<Point> points) {
        vector<Vector> vectorField;
        for (Point P : points) {
                Point Q = trajectory.nearestPoint(P);
                double d = distance(P, Q);
                double f = falloff(d, alpha);
                Vector v_pq = calculate_vector(P, Q);
                Vector v_qt = trajectory.tangentVector(Q);
                Vector v_p = v_pq + v_qt;
                Vector V_P = f * v_p;
                vectorField.push_back(V_P);
        }
        return vectorField;
}
```

Bio-Data Integration

Based on our conceptual framework, we integrate bio-data into the artistic representation of calligraphy, offering a unique introspection into the creative process of the calligrapher. This integration extends the boundaries of conventional art interpretation. The artwork (A) transitions from reflection of the artist's artistic knowledge (K) and artistic exploration (E) to a deeper embodiment of their cognitive capability (C).

In this project, we incorporate the calligrapher's bio-data, captured during the writing process, into the calligraphy visualization. The fusion transforms traditional calligraphy into an expressive medium that communicates the artist's inner experiences.

In our project, we capture specific bio-data to visualize the calligrapher's focus, pressure, and muscular control. We use two devices to capture these data: a consumer EEG headband from Flowtime [35] and an EMG sensor from Biometrics [36].

The EEG headband measures the brain waves (α, β, θ, δ, γ) of the calligrapher using eight sensors that capture the EEG signals of the left and right channels. This device operates at a bandwidth of 250 Hz and can detect brain activities from -2uv to 2uv. The headband connects to our software, which is built with Python and Flowtime's software development kit (SDK), via Bluetooth and sends the raw data to Flowtime's Emotion Cloud for processing. The Emotion Cloud returns key measures of attention, relaxation, and pressure, which range from 0 to 100, every 600 milliseconds.

The EMG sensor records the electromyogram data of the calligrapher's arm muscles using six sensors attached to the right arm (two on the upper arm and four on the forearm) (Fig. 4). The muscle groups extensor digitorum, flexor carpi radialis,

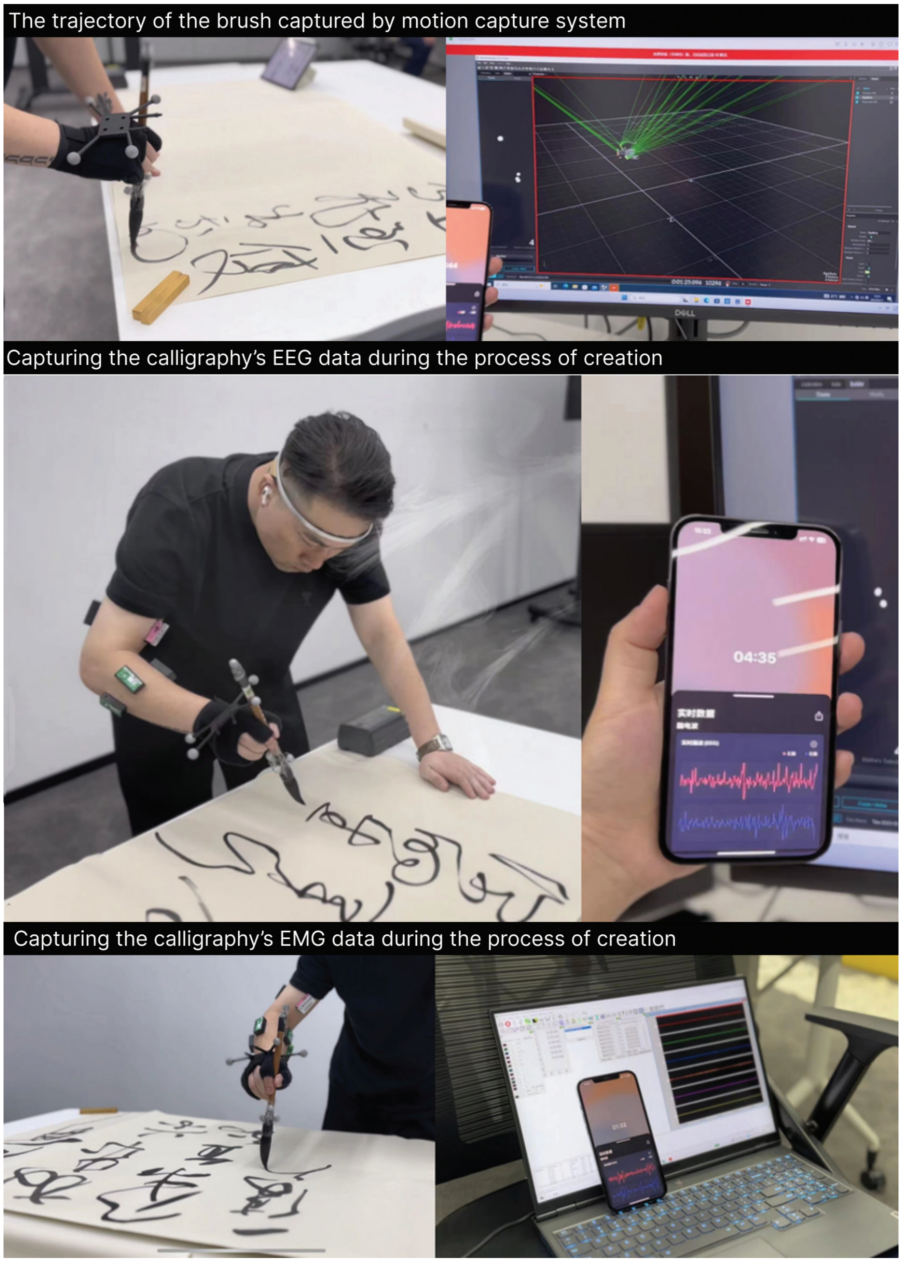

Fig. 4. The trajectory of the brush captured by motion capture system. (© Rem RunGu Lin)

and triceps brachii play a critical role in the control and accuracy of the calligrapher's arm and hand movements. The EMG sensor has a bandwidth of 10–490 Hz, recording muscle activities within a range from +/– 60mV to +/– 6000mV. Although the sensor records data continuously at half-millisecond intervals, our system samples this information every 600 milliseconds to align with the EEG data, focusing on a functional range of –200mV to 200mV for our analysis.

Our software receives these indicator values, converts the data into Open Sound Control (OSC) format, and transmits them to the Unreal Engine using the User Datagram Protocol (UDP). To meaningfully incorporate the bio-data into the visualization, we establish the following rules, thereby adjusting the parameter (P) through the neurofeedback mechanism:

EEG Attention—Brightness: The brightness of the particles is directly tied to the calligrapher's attention level. To amplify the visual impact, we scale the attention indicator from a 0–100 range to a 0–2 brightness level for the particle shader.

EEG Pressure—Background Color: Pressure level changes corresponding to color variations, with a low pressure being blue and high pressure being red.

Extensor Digitorum EMG—Particle Emission Rate: Muscle activities from the extensor digitorum are quantified to adjust the particle emission rate. The higher an activity, the greater the emission rate, ranging from 100 to 500, correlating with the artist's focus and precision in each stroke.

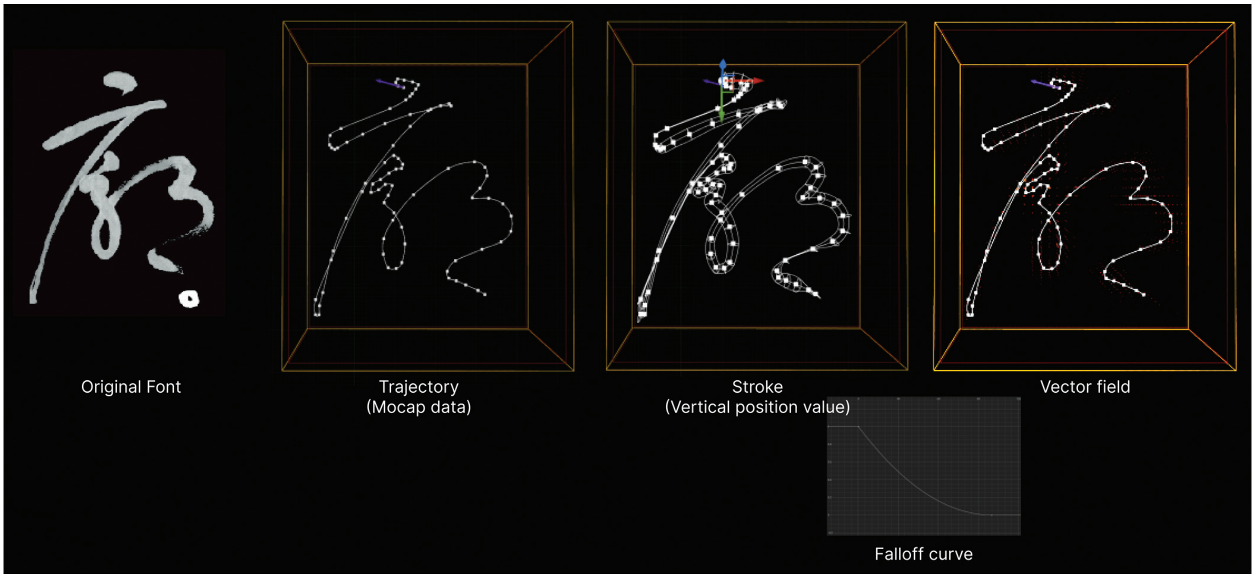

Fig. 5. Generating the vector field of cursive calligraphy. (© Rem RunGu Lin)

Flexor Carpi Radialis EMG—Frequency of Curl Noise: The frequency of curl noise is inversely proportional to the muscle activity of the flexor carpi radialis; more activities mean a smoother, more stabilized frequency. We remap each activity scale from 0 to 200 to an inverted range of 10–0, affecting the intensity of the curl noise.

Triceps Brachii EMG—Particle Size: The triceps brachii's activity informs the size of the particles; more muscle effort leads to larger particles, embodying the strength and energy exerted in each stroke. We adjust the size of the stripe particles by mapping the activity range of 0–200 to a size range of 0.7–1.2.

This mapping prioritizes the aesthetic and interpretive effects of the artwork over strict scientific visualization.

Ink Visualization

The nature of calligraphy goes beyond the visual strokes on a surface. It embodies depth, motion, and emotion. Visualizing this art form in a 3D space enhances the appreciation and understanding of the calligrapher's artistic exploration (E) and cognitive capability (C).

By simulating ink particles in motion along the vector field derived from the brush's trajectory and the falloff curve, we create a dynamic representation of the ink flow and artistic expression (Fig. 5). What sets our method apart is the integration of neurofeedback from the calligrapher. This fusion creates bio-ink, transforming artistic knowledge (K) and cognitive capability (C) into a tangible form.

To visualize the stroke movement, we create a particle system in Unreal Engine 5, a widely used real-time 3D creation platform. The process begins with the formation of small tubes in space by particles. These particles not only expand temporally during their trajectory but also are modulated in aspects such as brightness, size, emission rate, and inherent noise, each a reflection of the calligrapher's neurofeedback, embodying the parameter (P) (Fig. 6). This creates a dynamic representation of the stroke movement in 3D, simulating the fluidity and aesthetic appeal of traditional ink strokes.

Sensor	Indicator	Parameter	Relationship
EEG	Attention	Brightness	AT (Low) AT (High)
	Pressure	Background color	PR (Low) PR (High)
EMG	Extensor Digitorum	Rate	ED (Low) ED (High)
	Flexor Carpi Radialis	Noise frequency	LCR (Low) LCR (High)
	Triceps Brachii	Size	TB (Low) TB (High)

Fig. 6. Rules for incorporating bio-data into the visualization. (© Rem RunGu Lin)

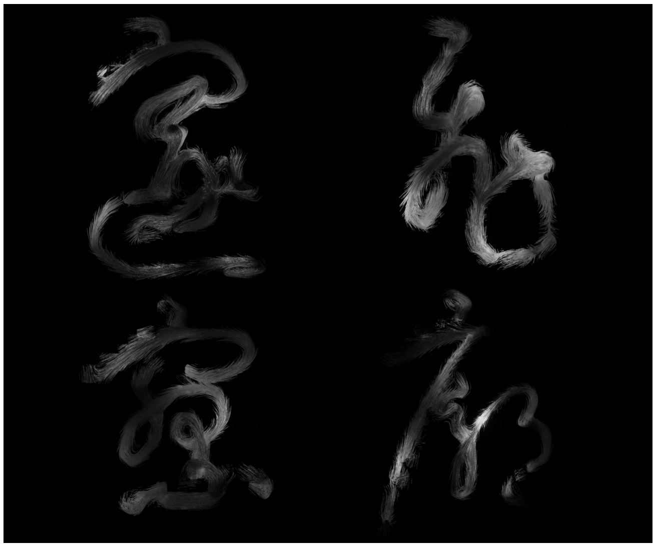

Fig. 7. The visualization of cursive calligraphy in 3D. (© Rem RunGu Lin)

The resulting visualization captures the nuances of the calligrapher's brushwork and creates a vivid experience for the viewer (Fig. 7). One can perceive the artistic exploration (E) and cognitive capability (C) in the calligraphy with multisensory appreciation.

Dynamic 3D Artwork

Traditional calligraphy is often confined to a 2D plane, which may not fully capture the essence of the complex and fluid movements of the ink brush. The movements of the ink brush encompass a 3D space when Chinese calligraphy is written, and these intricacies can be lost when presented only in 2D [37]. We break the 2D restriction and create dynamic 3D calligraphy that enhances the audience's experience and deepens their understanding of the art form.

In an inspiring fusion of technology and tradition, our work was featured in the Guangzhou New Year Poetry Festival, projected on the façade of Guangzhou Library. Embracing the theme of Life, we collaborated with the talented calligrapher Yanbin Fu, who penned a poem by Eugénio de Andrade in a cursive style. By capturing the motion and bio-data, we regenerated Fu's calligraphy into a dynamic 3D artwork. The festival also saw our project extended into a partnership with a modern dance group called ZhiRen, culminating in a performance that melded traditional calligraphy with contemporary dance, all set within the immersive environment we created (Fig. 8).

CONCLUSIONS AND FUTURE WORK

This paper has presented a generative approach to creating immersive and dynamic 3D calligraphy artworks. By systematically combining the visualization of stroke and ink movement with the calligrapher's bio-data, we create a vivid representation of calligraphy and initiate a dialogue between the artist's internal world and external expression.

Building on this foundation, future endeavors may include:

1. **Data Analysis and Visualization:** Developing a more robust and effective method to analyze and visualize EEG and EMG data in relation to the writing movement.

Fig. 8. Performance at Guangzhou New Year Poetry Festival. (© Rem RunGu Lin)

2. **Bio-Data Expansion:** Investigating the incorporation of other bio-data types, such as breath rate, heart rate, or skin conductivity, to provide a more comprehensive understanding of the artist's physical and emotional states during the creative process.
3. **Educational Development:** Developing an educational tool, allowing the audience to gain a deeper appreciation of the intricacies involved in creating calligraphy and fostering a better understanding of the artist's intentions and emotions.
4. **Therapeutic Applications:** Investigating the potential use of our immersive 3D calligraphy technique as a therapeutic tool. The intersection of artistic expression, bio-data visualization, and 3D interaction could pave the way for therapeutic interventions to facilitate emotional healing, mindfulness, and self-reflection.
5. **Broadening Scope:** Expanding the application of our methodology to other traditional art forms, such as painting or sculpture, where similar immersive and interactive experiences could enhance the audience's understanding and appreciation of the artworks.

In conclusion, our approach to generating immersive dynamic 3D calligraphy has demonstrated promising results, offering an engaging way to appreciate and understand the art form. The potential applications of our method extend beyond calligraphy, with the integration of bio-data and 3D visualization techniques potentially benefiting other art forms such as painting and sculpture. Future research could explore the combination of traditional art forms with modern digital technologies further, paving the way for new possibilities in artistic expression and exploration. Additionally, investigating the impact of our approach on the learning and skill development of artists in various disciplines may provide valuable insights into the creative process and foster deeper connections between the audience and the artist.

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