Research in Physical Education, Sport and Health
2024, Vol. 13, No. 2, pp.77-81
ISSN(Print):1857-8152; ISSN(Online):1857-8160

# INTEGRATING EXERCISE, ARTS AND SCIENCE. COMPUTER-GENERATED DYNAMIC HOLOGRAMS FOR VISUALIZATION OF COMBINED AMBIENT SIGNAL SOURCES

DOI:
*(Original scientific paper)*

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***Abstract***

*We propose an interactive system designed to generate dynamic, computer-assisted holograms imbued with inherent aesthetic qualities. These holograms are synthesized from a diverse range of ambient input sources, including acoustic signals (terrestrial sources), mechanical-electrical inputs (bodily sources), and electromagnetic signals (cosmic sources). This system facilitates a novel form of conceptual aesthetic expression by incorporating an integrated biofeedback mechanism aimed at enhancing perceptual-motor control, thus enabling the interactive and adaptive co-creation of aesthetic visualizations. The innovation of this system lies not merely in the 3D visualization of fractal or oscillatory patterns, but in its capacity for interactive mapping that transforms a broad spectrum of primarily non-visual, ambient structural sources into visual aesthetic experiences. On a deeper level, these aesthetic experiences embody the fundamental unity of phenomena that may initially seem disparate. At its core, this system reflects the adaptive, synergistic coordination between human activity and natural processes, resulting in the creation and appreciation of aesthetically refined outputs. The holograms may serve as educational instruments, crafted to elucidate the overarching concept of unity within diversity. In a similar vein, they can be conceived as aesthetic dynamic iconographies for institutional interiors or urban public spaces, tailored to meet the specific architectural requirements of the locale.*

***Key words:*** *computer-generated hologram, aesthetic affordances, education technology, movements, arts, ambient noise,*

## Introduction

In his seminal work *Opticks*, originally published in 1704, Isaac Newton posited that "Nature is very consonant and conformable to herself," a statement reflecting the notion that the laws governing natural processes exhibit inherent coherence both within themselves and in their mutual relationships (Newton, 1952). This concept of an underlying unity amidst apparent diversity has since become a foundational idea driving the advancement of modern science.

However, movements, art and science are also intrinsically united in their shared pursuit of patterns. This pursuit is governed by an ongoing dialectic of constraint and action, which generates patterns that evoke the numinous, the beautiful, and the awe-inspiring. In every action, the preceding movements impose constraints on those that follow, whether in planetary motion, dance, or athletic performance. Actions, in this context, can be understood as dynamic processes of morphogenesis, unfolding and reshaping themselves over time.

The human body as a medium of expression creates innumerable movement forms always under a set of changing and interacting constraints such as those coming from the environment and the individual. It is the interdependence of constraints and movement forms that is responsible for the transition of human actions from the realm of undifferentiated possibilities into concrete actuality (Hristovski, 1989). The interplay of actions and constraints shapes the nature of actuality, the nature of what we witness at each moment in time.

In the practices of painting and sculpture, the artist shapes and molds space through the interplay of action and constraint. These creative processes are fundamentally pattern-forming, wherein each stroke of the brush or carve of the chisel becomes a defining gesture, a detail that constrains the subsequent actions. In

this way, the future is created—an emergent sequence of possibilities arises, shaping the adjacent possible. The artwork itself emerges from this perpetual cycle of strokes and constraints.

Similarly, in music, the chord progression and notes that have preceded constrain those that follow, creating a temporal and harmonic structure that dictates which melodic patterns may be realized within a given interval. The relationships between symbols and their meanings in mathematics and language exhibit analogous behaviors: through actions constrained by prior ones, they give rise to patterns that shape our understanding and emotional responses.

In all these domains—music, mathematics, sports, storytelling, and poetry—the generation of patterns, driven by the interplay of action and constraint, molds both thought and emotion. Each of these processes converges toward unique stabilized patterns or, at times, meanders between them, guided by an inherent structure that is not arbitrary. These patterns, whether in mathematical equations or artistic expression, hold an undeniable aesthetic appeal.

Patterns signify non-homogeneity and broken symmetry (Nicolis and Prigogine, 1981) — states in which what emerges and follows is not random, but constrained by the structure of prior events. This suggests the existence of information and order within a system. In a broader sense, both art and science can be seen as expressions of preference, both manifesting as constraint-driven processes of pattern discovery. In this respect, art becomes a form of science, and science, in turn, becomes a form of art.

The objective of this brief prospectus is to outline and propose an interactive system for the generation of dynamic, computer-assisted holograms with inherent aesthetic qualities, synthesized from ambient input sources of diverse natures, including acoustic inputs (terrestrial sources), mechanical-electrical inputs (bodily sources), and electromagnetic signals (cosmic sources). The system facilitates a novel form of conceptual aesthetic expression, incorporating an integrated biofeedback mechanism designed to enhance perceptual-motor control capabilities, thereby fostering interactive, adaptive co-creation of aesthetic visualizations. The innovation of this idea resides not in the mere 3D visualization of fractal or oscillatory patterns, but in the potential for interactive mapping that transforms a vast array of mostly non-visual, ambient sources of structure into visual aesthetic experiences. At a more profound level, these aesthetic experiences encapsulate the underlying unity of phenomena that may initially appear distinct. The core idea of this system lies in the adaptive joint coordination between human activities and other natural processes, culminating in the creation and appreciation of aesthetically refined outputs.

**Patterns of ambient signal sources. Periodicity, Gaussian noise and Brownian motion**

Ambient signal sources refer to localized processes that produce signals of various types, including acoustic, electromagnetic, or mechanical phenomena. Natural patterns coming from these sources can be broadly categorized into three types: periodic, quasiperiodic and aperiodic. Periodic and quasiperiodic patterns, exemplified by crystals, quasicrystals, rhythmic movements, periodic variable stars, seasonal changes, etc., exhibit discrete spectral characteristics, whereas aperiodic patterns display broadband spectra, typically referred to as Gaussian noise and Brownian motion. For instance, active galactic nuclei, solar flares, supernova remnants (Oka et al., 2018; Vukicevic-Karabin, 1994), isometric exercises (Hristovski and Balagué, 2010; Vázquez et al., 2016), waterfalls, and comparable phenomena exhibit spectral indices that categorize them within a continuum ranging from Gaussian noise to Brownian motion.

Certain ambient sources, such as active galactic nuclei, generate fractal visual patterns that remain stable over extensive time scales. In contrast, the local ambient sound of rivers and waterfalls fluctuate in response to variations in water abundance, transitioning intermittently from a predominantly noisy texture, characteristic of foamy turbulent flow, to a more tonal quality that suggests the presence of periodic components. These transitions occur over time scales of several months. Consequently, the three-dimensional iconographic visual content of the hologram corresponding to these changes in rivers is expected to evolve from intricate, fractal patterns to more oscillatory, Lissajous-like or crystal-like structures. Furthermore, the sounds of sea or ocean waves will produce fractal patterns that undergo more rapid transformations, operating on time scales that approximate the dynamics of human movement control (e.g. Vázquez et al., 2016).

**Method**

*Sources of input and preprocessing*

As illustrated in Figure 1, input sources can consist of time series derived from various bodily and environmental sources. These signals can be acquired in real-time through dedicated sensor systems or

alternatively, they may be sequentially collected or simulated and subsequently utilized as input. Given that these sources may exhibit periodic or aperiodic characteristics, their spectral properties will dictate the software's management of the time series data. The initial step involves subjecting the time series to Fourier analysis to identify its spectral type and to derive quantitative descriptors. For instance, the power-law spectra typical of noise and Brownian motion exhibit distinct qualitative and quantitative properties when compared to periodic or quasiperiodic time series. Since both the preprocessing phase and subsequent stages must be conducted in real-time, it is likely that these computations will necessitate the use of cloud computing resources.

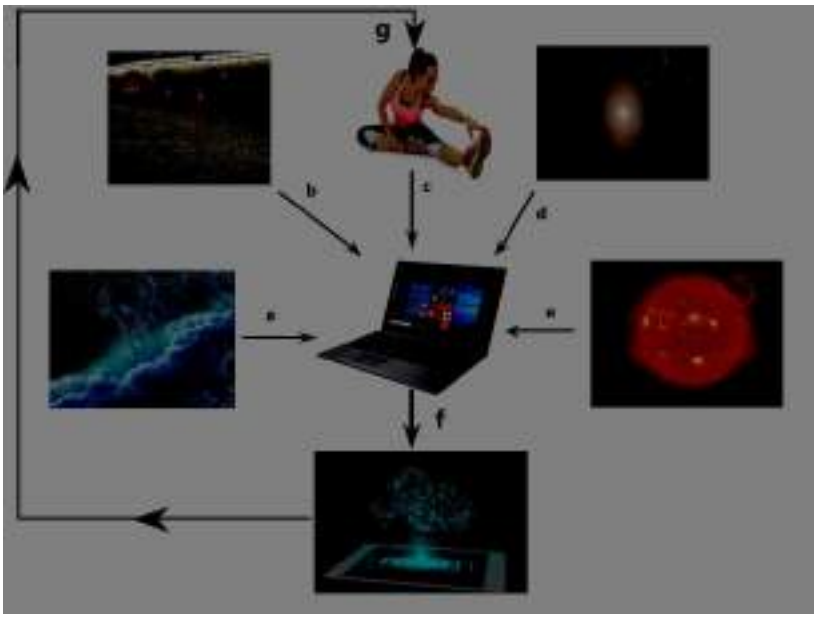


Figure 1. The system for generating computer-assisted holograms (denoted as output f) integrates various ambient input sources, including aquatic sound sources (a and b), movement coordination and control-related mechanical or electric ambient sources (c), cosmic electromagnetic environmental sources (d and e) and g - the general feedback from the hologram to the perceiver-artist. The content of the holograms will be determined by the properties of the source time series. These may manifest as terrains, landscapes, clouds, plants, or lightning, as well as Lissajous figures or their sequential and parallel combinations. While perception-action-related ambient sources may be deliberately manipulated by humans through the loop g, other forms of input emerge spontaneously within natural contexts.

**Generation of visual content and the holograms**

The generation of visual content from aperiodic time series exhibiting power-law spectra is influenced by the numerical value of the power, which determine the structural elements of the visual output, such as terrains, landscapes, clouds, plants, and lightning. Open-source software tools, such as Artifex Terra 3D, may be utilized for this purpose. For periodic time series, existing open-source platforms, including those available on GitHub, can be employed. Once the visual content is generated in real-time, recently developed Computer-Generated Holography (CGH) technologies, such as those presented by Shigematsu et al. (2024) and Lee et al. (2024), can be applied to produce dynamic holograms in real-time.

**Function and the aesthetic affordance biofeedback**

The function of the holograms can be conceptualized as a form of decorative art, tailored to the interiors of institutions or public squares, in accordance with the specific demands of local architecture. Additionally, these holograms may serve as educational instruments, designed to visually represent the unifying theme of diversity within unity. Through the rendering process, the 3D visualizations can adopt various stylistic approaches, including impressionistic, expressionistic, or realistic forms, and these styles may be interchanged dynamically. The system is capable of autonomously generating visually engaging scenes in a non-interactive manner, reflecting the spontaneous fluctuations in ambient noise from diverse sources, as previously discussed. However, given the system's potential for interactivity (as depicted in Fig. 1, loop g),

the perception-action feedback loop offers opportunities for active engagement by individuals in the ongoing process of artistic creation. This aesthetic biofeedback system facilitates the learning of 3D holographic iconography control through the simultaneous perception and enactment of aesthetic affordances (Sánchez, 2022), which denote opportunities for action. Its purpose is to cultivate both perceptual attunement to the aesthetic qualities of the 3D visualizations and the development of both gross and fine motor skills. The perceiver-artist is thereby compelled to attune themselves to the dynamic progression of nested affordances over time. Similar to the mastery required by painters or musicians, whose proficiency in perceptual and motor skills is crucial to effective performance in their respective art forms, practitioners within this aesthetic domain must hone the ability to adaptively synchronize their actions with ambient noise inputs. Furthermore, they must possess the capacity to deliberately sustain or modify the visualizations, ensuring that the artistic performance of the entire system remains of the highest caliber.

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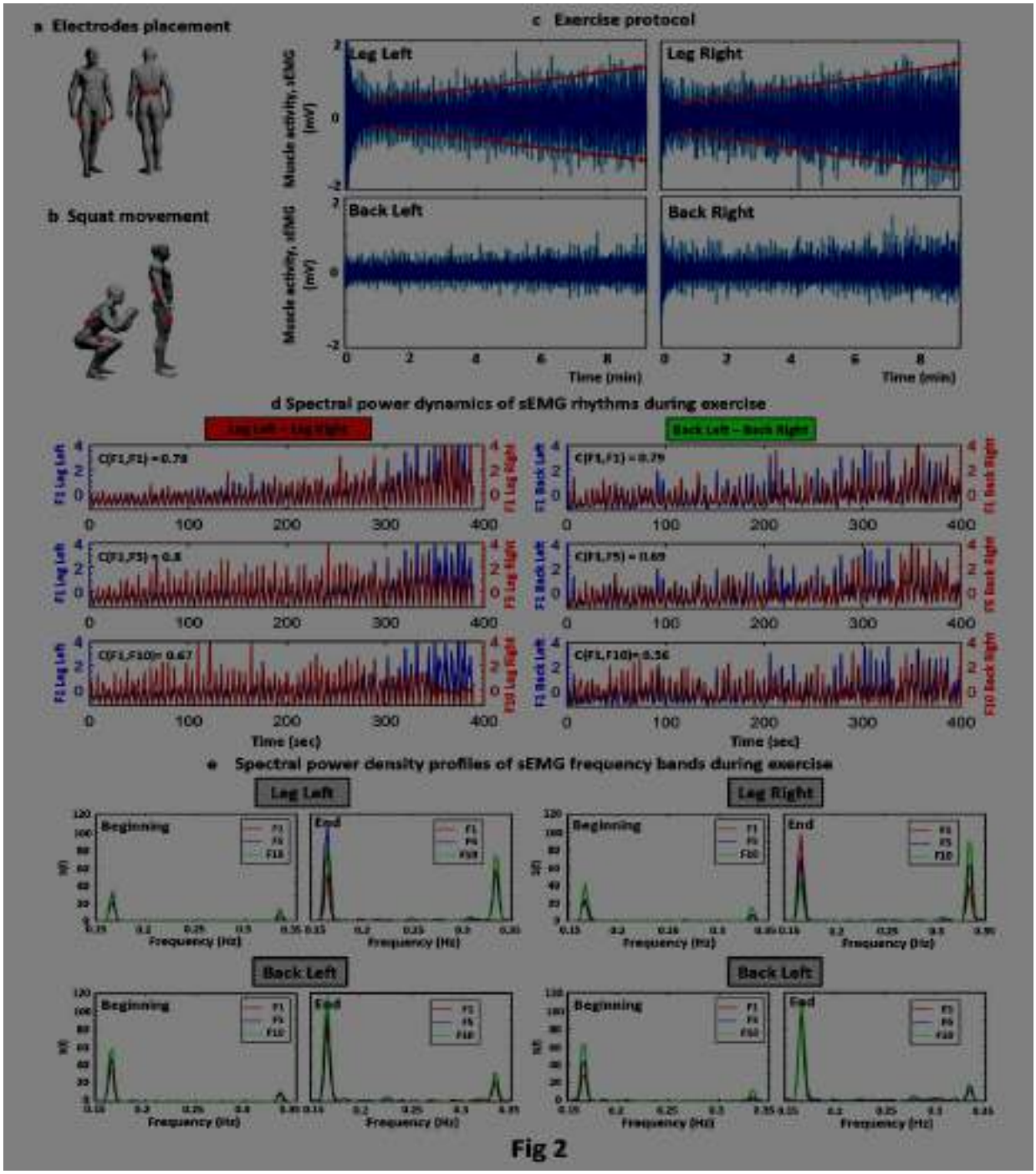
a Electrodes placement
b Squat movement
c Exercise protocol
Leg Left
Leg Right
Back Left
Back Right
Muscle activity, sEMG (mV)
Time (min)
d Spectral power dynamics of sEMG rhythms during exercise
Leg Left – Leg Right
Back Left – Back Right
Time (sec)
e Spectral power density profiles of sEMG frequency bands during exercise
Beginning
End
Frequency (Hz)

Fig 2