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Article

Inertial Motion as a Self-Synchronized Field: A Wave Interpretation of Inertia, Kinetic Energy and Long-Range Interactions

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Abstract

We propose a unified interpretation of inertial motion and long-range interactions where a particle is not a localized point, but the focus of a coherent field of standing or quasi-standing waves. Inertia emerges from the phase rigidity of this deformed field, kinetic energy from its deformation energy, and electromagnetic and gravitational forces point toward the current position of sources through energy transport or geometry along self-aligned quasi-standing waves. This perspective, compatible with special relativity, classical electrodynamics and general relativity, connects mechanics, electromagnetism and gravitation through the principle of wave self-synchronization.

Keywords: self-synchronization; standing waves; inertia; kinetic energy; quasi-standing wave; electromagnetic field; photon; Liénard-Wiechert; general relativity

1. Introduction

Inertia is a postulate in classical mechanics: a particle in uniform motion maintains its velocity. We show here that it emerges from an extended wave structure: a particle is the focus of OUT waves (emitted now) and IN waves (from past emissions), forming a self-sustained coherent field that slides as a whole at constant velocity. This wave-based perspective resonates with early interpretations of matter waves [1] and standing wave models of particles [4], while providing a specific mechanism for inertial behavior.

The self-synchronization mechanism proposed here finds a mathematical analogy in the Kuramoto model [3], where a population of weakly coupled oscillators spontaneously locks into a common phase. In our framework, the elementary wave emitters constituting the field play the role of Kuramoto oscillators, with their mutual interactions through the medium leading to the emergence of a globally coherent wave pattern that moves as a whole.

2. The Particle as a Wave Focus

Consider a particle moving with velocity $\mathbf{v}$. At time t , it emits spherical OUT waves:

$$\psi_{\text{OUT}}(\mathbf{r}, t) = \frac{A}{|\mathbf{r} - \mathbf{r}_s(t)|} \exp(i(k|\mathbf{r} - \mathbf{r}_s(t)| - \omega t))$$

The IN waves represent the feedback field converging toward the particle. They originate from past emissions and are essential for forming the stationary pattern. The retarded potential formalism used here follows the classical treatment of moving sources [9,10]. They can be conceived as the sum of retarded contributions, where each past emission at time t_e and position $\mathbf{r}_s(t_e)$ contributes to the IN wave at point $(\mathbf{r}, t)$ according to a coherent time-reversal principle.

This extended wave structure naturally accounts for the ****non-local character**** of quantum particles, as demonstrated by Alain Aspect's experiments testing Bell's inequalities [15] and manifested in interference patterns in double-slit experiments [16]. The self-synchronization mechanism proposed

here finds a mathematical analogy in the Kuramoto model [2,3], where a population of weakly coupled oscillators spontaneously locks into a common phase. In our framework, the elementary wave emitters constituting the field play the role of Kuramoto oscillators, with their mutual interactions through the medium leading to the emergence of a globally coherent wave pattern that moves as a whole.

Mathematically, this is encapsulated in the general solution of the wave equation with a moving source:

$$\Psi(\mathbf{r}, t) = \int dt_e G(\mathbf{r}, t; \mathbf{r}_s(t_e), t_e) \cdot S(t_e)$$

where G is the retarded Green's function of the wave equation and $S(t_e)$ is the source emission at time t_e . The part of this integral that converges toward the source trajectory constitutes the IN field.

The schematic superposition of this IN field with the instantaneous OUT wave forms quasi-standing waves along the trajectory:

$$\Psi(\mathbf{r}, t) \sim \psi_{\text{OUT}} + \psi_{\text{IN}} \Rightarrow \text{quasi-standing waves if } v = \text{constant}$$

3. Energy Balance: Why No Energy Loss?

The average Poynting flux of standing waves is zero:

$$\mathbf{S} = \frac{1}{2\mu_0} \text{Re}(\mathbf{E} \times \mathbf{B}^*) = 0 \quad (\text{on average})$$

No net energy is radiated: the focus (particle) does not lose energy.

4. Field Deformation and Inertia

The deformation of the field Ψ can be visualized by considering the locus of past emission points that constructively interfere to form the IN wavefront at a given time. An illuminating thought experiment consists of reversing the propagation direction of all waves constituting the field at time t and observing the resulting interference pattern. The concept of inertia as a field property has historical roots in Mach's principle [5], though our approach provides a specific wave-mechanical implementation.

This pattern forms a closed vibrating "string" around the source trajectory. In the case of motion at constant velocity v , a geometric analysis shows that this string is not a circle, but exhibits a characteristic front-rear asymmetry. Its effective radius r as a function of the angle θ relative to the velocity vector is given by:

$$r(\theta) = \frac{\lambda_0}{4\pi\beta(1 - \beta \cos \theta)}, \quad \beta = \frac{v}{c}$$

This equation, which emerges from a stationary phase condition for the IN waves, captures the inertial deformation of the field:

- **Front** ($\theta = 0$): the term $(1 - \beta)$ in the denominator leads to a small radius of curvature. The field is "compressed" and waves are directed toward the future position of the source.
- **Rear** ($\theta = \pi$): the term $(1 + \beta)$ gives a larger radius of curvature, allowing "catching up" over longer range.

The field slides as a whole at velocity $\mathbf{v}$, and its phase rigidity manifests macroscopically as inertia.

5. Kinetic Energy = Deformation Energy

The total energy of the deformed field is:

$$E = \int |\Psi(\mathbf{r}, v)|^2 dV = E_0 + \underbrace{\Delta E_{\text{deformation}}(v)}_{\text{kinetic energy}}$$

The v^2 dependence emerges naturally from the field geometry. The limited expansion of the phase surface $r(\theta)$ shows that linear terms in β cancel by symmetry when integrated over the sphere, leaving only the quadratic contribution. Our deformation energy approach bears mathematical similarities to elastic energy calculations in continuum mechanics [12]:

$$\Delta E_{\text{deformation}} \propto \int_0^\pi \beta^2 \cos^2 \theta \cdot 2\pi r_0^2 \sin \theta d\theta \propto \beta^2 \propto v^2$$

The kinetic energy $\frac{1}{2}mv^2$ is thus identified with the spatial deformation energy of the wave pattern. This interpretation offers a tangible view of inertia as resistance to deformation of a coherent field structure.

6. Particle Collisions: Center of Mass and Inelastic Energy

During a collision, it is the deformation energy of the two fields that is redistributed. The center of mass is the point where energy density is balanced:

$$\mathbf{r}_{\text{cm}} = \frac{\int \mathbf{r} (|\Psi_1|^2 + |\Psi_2|^2) dV}{\int (|\Psi_1|^2 + |\Psi_2|^2) dV}$$

The energy released during an inelastic collision comes from the reorganization of internal deformation energies of the two particles. Denoting $E_{\text{deform},i}^{\text{init}}$ and $E_{\text{deform},i}^{\text{final}}$ as the deformation energy of particle i before and after collision, we have:

$$\Delta E_{\text{inelastic}} = \left(E_{\text{deform},1}^{\text{init}} + E_{\text{deform},2}^{\text{init}} \right) - \left(E_{\text{deform},1}^{\text{final}} + E_{\text{deform},2}^{\text{final}} \right)$$

Unlike classical theories where this energy is attributed globally to the system, this model allows in principle determination of each particle's contribution to the released energy. The percentage from particle 1 would be:

$$\%_1 = \frac{E_{\text{deform},1}^{\text{init}} - E_{\text{deform},1}^{\text{final}}}{\Delta E_{\text{inelastic}}} \times 100$$

This distinctive prediction of the model could be tested in specific collision experiments.

7. Electromagnetism: The Interaction Mediator as a Self-Aligned Quasi-Standing Wave

The electromagnetic field of a charge in uniform motion slides as a whole:

$$\mathbf{E}(\mathbf{r} + \mathbf{v}\Delta t, t + \Delta t) = \mathbf{E}(\mathbf{r}, t)$$

The force on a test charge points toward the current position of the source [9].

The photon, mediator of the electromagnetic force, is not an isolated point particle. It corresponds to energy transport along a coherent wave train—a **quasi-standing wave** formed by the superposition of OUT waves emitted at each instant and IN waves resulting from their progressive reflections in the surrounding fields.

As with the particle itself, this superposition creates a rigid wave pattern where the net energy flux is zero in the absence of acceleration—explaining the absence of energy loss through continuous radiation. The IN waves are the retarded echoes of past emissions, captured in a coherent channel that **slides as a whole with the moving source**. It is this self-synchronization that continuously aligns the pattern with the current position of the charge, causing the force to point in the correct direction.

8. Gravitation and Electromagnetism: Unification Through Quasi-Standing Waves

Photons emitted by the Sun take approximately 8 minutes and 20 seconds to reach Earth. Yet, the gravitational force that maintains our planet in orbit points toward the **current position of the Sun**,

not the position it occupied at the time of the observed light emission. This phenomenon reveals the profound nature of interaction transport, whether electromagnetic or gravitational.

In general relativity, the presence of mass-energy deforms spacetime. This deformation results from the coherent superposition of quasi-standing waves associated with moving matter. The geometric interpretation of gravity naturally aligns with the framework of general relativity [6,14]. The **local energy density gradient** thus generated in space deflects the propagation of all waves—including those constituting particles.

These waves, continuously self-aligned with their source, form a global deformed field that moves as a whole. It is this local energy density gradient, not an exchange of virtual gravitons, that orients the trajectory of bodies—and does so toward the current position of the source.

Electromagnetism and gravitation therefore rest on a common mechanism:

a **self-synchronized wave field**, sliding as a whole, whose structure determines the direction of interaction.

The difference lies in the nature of the coupling:

- Electromagnetism involves energy transport (acceleration → radiation).
- Gravitation, in inertial regime, acts through pure field geometry—without dissipation.

9. Conclusion

A particle is the focus of a field of standing or quasi-standing waves. Inertia is the phase rigidity of this deformed field. Kinetic energy is the spatial deformation energy. Electromagnetic and gravitational forces are mediated by self-aligned quasi-standing waves—with or without energy transport. Inertial motion is a self-sustained coherent state.

This vision unifies mechanics, electromagnetism and general relativity through a single principle of wave self-synchronization.

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