Transmission Imaging for Medical Applications

Tech ID: 34658 / UC Case 2026-597-0

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OTHER INFORMATION

KEYWORDS

QAPI, Quantum-Assisted Photon Imaging, photon, photons, signal-to-noise ratio, SNR, cadmium zinc telluride, CZT, quantum, imaging, medical imaging, Poisson, Binomial, annihilation, high-energy photons, ghost imaging, transmission imaging, quantum-assisted transmission imaging, quantum correlation, quantum-based, quantum PET, coincidence detection, coincidence

CATEGORIZED AS

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  - Medical
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RELATED CASES

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BACKGROUND

Quantum-correlated photon imaging experiments first used pairs of entangled photons so that an image was recovered only from correlations between the two detection paths rather than from either beam alone. Similar correlation and entanglement ideas have been attempted for higher energies and to positron-annihilation photons, motivating quantum-based Positron Emission Tomography (PET) concepts in which the additional quantum information carried by annihilation photon pairs could enhance image quality or add new types of contrast beyond conventional PET. In parallel, quantum-inspired transmission imaging has been proposed as an alternative to Computed Tomography (CT), which today relies on a well-characterized but fundamentally stochastic X-ray source, and is limited by Poisson photon statistics, dose requirements, and capped contrast for soft-tissue. Traditional X-ray and CT imaging are governed by Poisson statistics, where independent, random photon arrivals make the variance equal to the mean, and has fundamentally bound SNR for a given dose. Research on quantum-correlated transmission schemes has looked at image formation with higher-order correlations between photons (rather than simple independent counting) such that performance is no longer capped by standard Poisson statistics, which can in principle lead to superior SNR and sharper anatomical detail at a given dose.

To date, quantum-based X-ray implementations of this idea have largely relied on spontaneous parametric down-conversion (SPDC) to generate entangled or correlated photon pairs, but SPDC at X-ray-level energies has extremely low conversion efficiency and pair rates—often only a few pairs per second—rendering such medical or biological imaging impractical. Quantum correlation of Annihilation Photon Imaging (QAPI) brings the correlation concepts into a PET-like regime by using positron annihilation as a bright source of 511 keV gamma-ray pairs while assuming a transmission-imaging role similar to CT. QAPI is designed to exploit the strengths of both worlds: unlike CT, it can count the incident annihilation photons via the idler channel and operate in a high-transmission regime that permits binomial transmission statistics. The PET-like 511 keV photons introduce challenges that do not exist for CT, including low interaction probability in tissue and detectors, reduced single-photon detection efficiency, and the need for precise coincidence timing between the signal and idler counts. For any high-energy, photon-based imaging, including emerging quantum schemes, there is a fundamental tension between dose (especially for biological tissues that are highly susceptible to damage, cell death, or mutation when exposed to ionizing radiation) and the photon statistics needed for adequate SNR. Moreover, the dose-normalized performance for quantum approaches is still not well established.

TECHNOLOGY DESCRIPTION

To help address these challenges, researchers at UC Santa Cruz (UCSC) have developed a new transmission imaging paradigm that combines positron-annihilation gamma pairs with ghost-imaging-style idler/signal normalization, where the number of photons emitted is known exactly (counted via the idler) and and transmission is binomial rather than Poisson. Using matched Monte Carlo simulations (Geant4 Application for Tomographic Emission or GATE) the results show a significant statistical advantage in both idealized and realistic room-temperature semiconductor material-based detector models (e.g., Cadmium Zinc Telluride or CZT) with SNR improvement approaching a factor of 2 relative to classical 511 keV and 70 keV imaging modalities under equivalent acquisition conditions, suggesting that QAPI can consistently outperform classical imaging under identical geometry and photon flux. Unlike many proposed quantum-imaging schemes that rely on idealized detectors, QAPI may retain a substantial performance benefit with commercially relevant room-temperature semiconductor technologies. Moreover, these research results suggest QAPI as a potentially more noise-efficient alternative to CT in breast or lung imaging, where modest attenuation currently limits low-contrast detectability even at non-trivial dose.

APPLICATIONS

- medical imaging
- surgical guidance
- therapy guidance
- research tooling

FEATURES/BENEFITS

- Direct counting of incident annihilation photons removes source-rate uncertainty and tightens noise statistics.
- Use of binomial rather than Poisson transmission statistics yields intrinsic SNR gain that grows as transmission increases, which can translate into better low-contrast detection.

- Coincidence-based QAPI approach replaces reliance on assumed or calibrated source intensity; eliminates source-rate fluctuations and non-physical transmission artifacts.
- Maintains theoretical SNR advantage in CZT detectors and mitigating key failure modes e.g., missed or mis-paired photons.

RELATED MATERIALS

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