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Muon scattering imaging of civil structures

Conventional non-destructive testing (NDT) techniques, such as ultrasound and X-ray imaging, exhibit critical physical limitations regarding penetration depth and contrast resolution when applied to thick, high-density civil structures [1]. To overcome these restrictions, scattering muography emerges as a viable alternative. By leveraging the continuous flux and high penetrating power of cosmic muons, this technique enables the non-invasive internal exploration of massive materials [2].

To implement this approach, a two-station hodoscope prototype is utilized, equipped with an external trigger system consisting of scintillator plates at both ends of the setup. The hodoscope's detection system comprises triangular plastic scintillators coupled with optical fibers and silicon photomultipliers (SiPMs), managed by a CAEN FERS-5200 data acquisition system [3], and achieves a joint detection efficiency of the trigger and scintillator matrices of approximately 61%. Applying a charge-centroid method to the acquired spectroscopic data, the hodoscope achieves an experimental spatial resolution of approximately 2.6–3.0 mm, corresponding to angular resolutions of approximately 0.52°–0.60° for scattering muography. A target sample is positioned between the two stations for subsequent three-dimensional reconstruction. Following signal filtering, the Point of Closest Approach (PoCA) and MuTrec trajectory reconstruction algorithms are applied, allowing for the mapping of density profiles and the detailed analysis of the sample's internal distribution [4].

The development of this instrumentation was initially guided by comprehensive Geant4 computational simulations, which modeled iron rebars embedded at depths of up to 60 cm within concrete blocks to establish the theoretical viability of internal element recognition. Following the physical assembly of the hodoscope in the laboratory, experimental imaging was conducted using lead blocks and custom civil engineering samples designed to evaluate the detection of varying iron bar thicknesses and to simulate a reinforced concrete mesh. Data acquisition periods of 20 days per sample yielded clear reconstructions capable of resolving rebars as thin as approximately 2 cm. Image quality was quantitatively assessed using SNR, CNR, MSE, and SSIM metrics; several post-processing filters, including noise deconvolution, were applied to the reconstruction algorithms, improving SNR and CNR by up to 3% and SSIM by up to 7%. These enhancements improved the visualization of the internal iron rebars, characterizing the imaging capabilities of the hodoscope and validating scattering muography as a promising technique for the non-destructive inspection of reinforced concrete structures.

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