

Study on Performance-Driven 3D Shape Generation Using Latent Space

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Generative artificial intelligence for three-dimensional shapes has recently attracted attention, but most studies focus on shape synthesis itself and do not sufficiently consider engineering performance. In conventional design, repeated CAD modeling, CAE analysis, and geometry modification make broad design-space exploration difficult. This study proposes a performance-driven 3D shape generation framework that connects shape and CAE performance in a shared latent space.

The target was a motorcycle engine clutch-cover geometry. A total of 4,207 training shapes, including augmented data from 1,199 original shapes, were encoded into latent vectors using a variational autoencoder (VAE). Principal component analysis (PCA) was then applied to construct a low-dimensional design space for exploration. Because PCA alone loses part of the information required for shape reconstruction, a conditional diffusion model was introduced to generate a high-dimensional latent representation from the first ten principal components. CAE performance indices, including the peak frequency and response level extracted from the equivalent radiated power (ERP) response, were mapped onto the same latent space.

The evaluation confirmed three points. First, shapes reconstructed using the PCA-conditioned diffusion model and VAE decoder provided ERP responses close to those of the original shapes, confirming that CAE performance was preserved after reconstruction. Second, PCA showed that the target geometry could not be represented by only a few principal components, indicating that shape information is distributed over multiple latent directions. Third, mapping CAE performance onto the latent space revealed that some principal components correlated with the first resonant frequency, whereas other components showed weak correlation.

Furthermore, interpolation between latent representations of two shapes with different frequencies generated a new shape with intermediate performance. Manipulating components with low performance sensitivity also produced geometry variations while maintaining nearly the same CAE response. These results indicate that latent directions with different levels of performance sensitivity can be visually distinguished and used for design exploration.

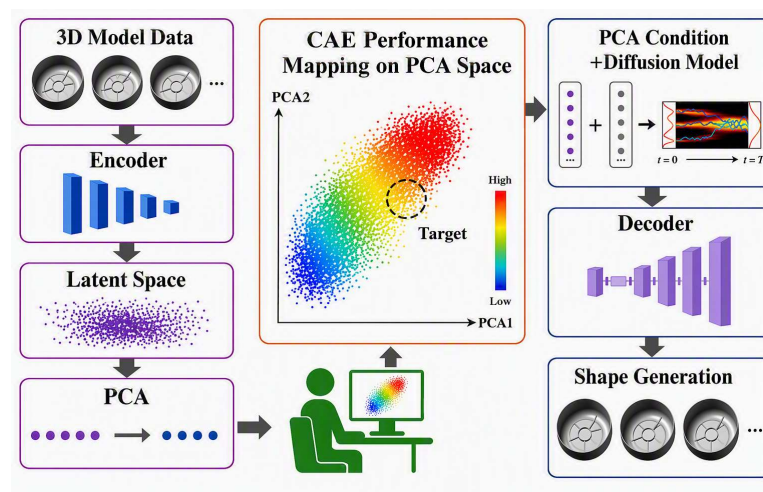


Fig. 1 Performance-driven 3D shape exploration using a latent performance map

In summary, the proposed framework combines VAE, PCA, diffusion modeling, and CAE performance mapping to realize performance-driven shape exploration. Unlike conventional latent-space visualization used mainly for model analysis, the framework provides an operational design space for visually tracing performance distributions and generating candidate geometries toward desired performance characteristics.