UDLS-3DPM: Automated uncertainty-aware deep learning solver for 3D particle morphology based on multi-view images

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Motivation

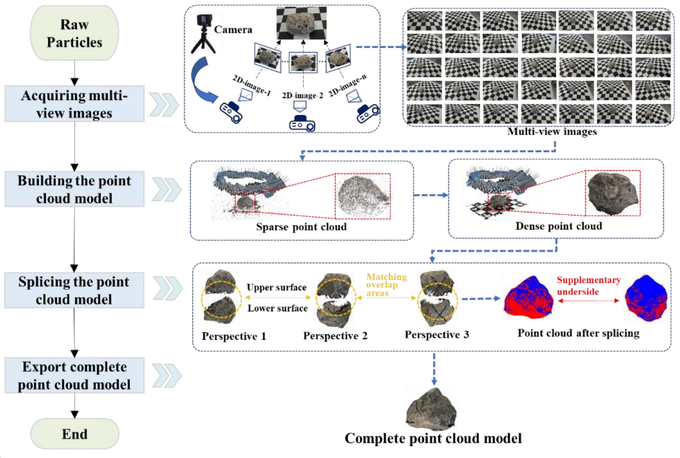
Over 200 years after Coulomb's studies, a general connection between the mechanical response of granular materials and the particles' morphology remains unknown[1,2]. Traditional particle morphology analysis often relies on single-view images, which have limitations in accurately **capturing 3D morphology**[3]. With the rapid development of **deep learning**, there is a growing need for automated and efficient morphology analysis tools. However, many deep learning models overlook data and model uncertainties. Thus, developing an automated, **uncertainty-aware** deep learning solver based on multi-view images is crucial for accurately analysing 3D particle morphology while considering these uncertainties.

Constructing the dataset

Handheld high-resolution action cameras were used to capture multi-view images of the particles.

The Structure from Motion-Multi-View Stereo (SFM-MVS) technique was employed to generate 3D point clouds of the particles.

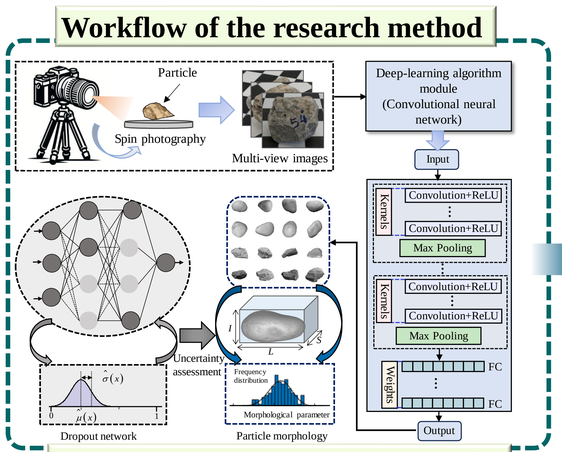
Point cloud computing methods, including algorithms for surface reconstruction and shape analysis, were used to calculate the shape indices of the particles.



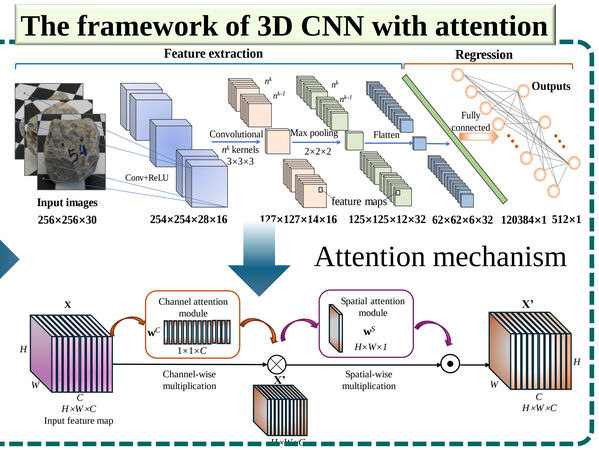
Uncertainty-aware deep learning

This research presents a deep learning framework with MC Dropout to reliably predict particle morphology from multi-view images.

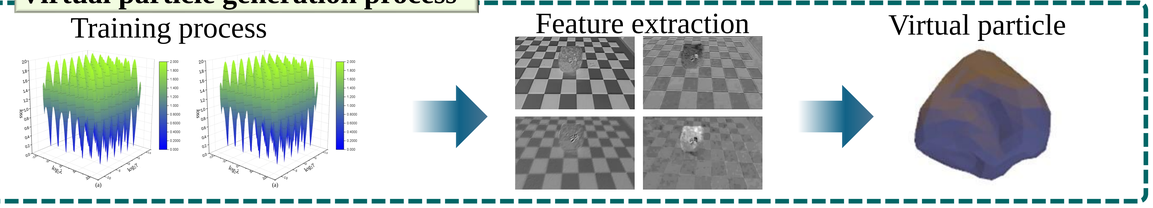
Workflow of the research method



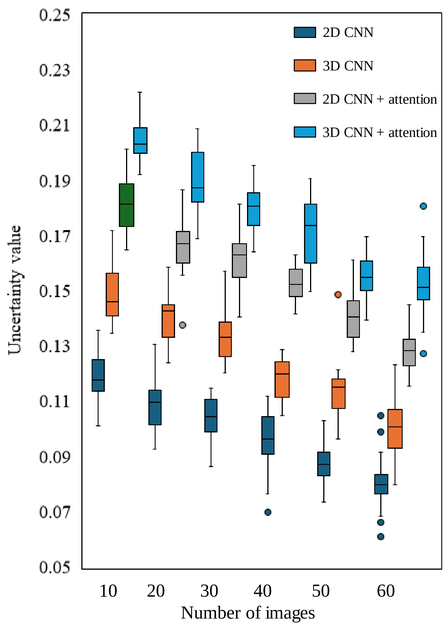
The framework of 3D CNN with attention



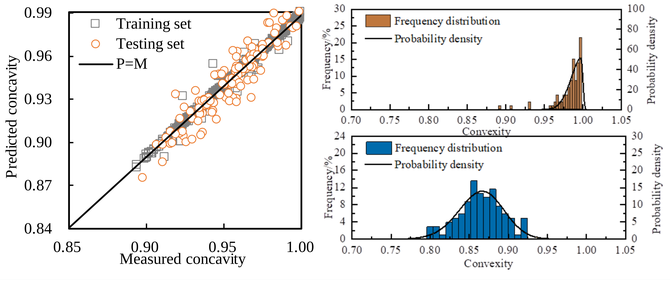
Virtual particle generation process



Results

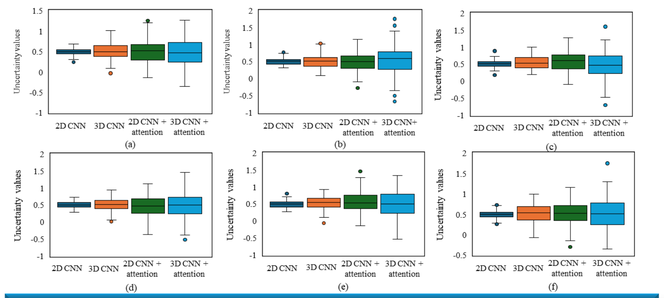


Each subfigure illustrates the relationship between actual values and predicted values, with data points closely distributed near the regression line, indicating a high consistency between model predictions and actual values. As the number of input multi-view images increases, the uncertainty of predictions from all models significantly decreases. This indicates that a larger quantity of particle image inputs leads to more accurate prediction results.



Discussions

- Attention mechanism raises uncertainty by focusing on local features.
- Large uncertainty in the roughness index indicates sensitivity to particle surface texture.
- Accuracy and uncertainty for particle morphology prediction should be balanced.



Conclusions

- The 3D CNN model with attention mechanisms effectively predicts the 3D morphology of particles, achieving high prediction accuracy with an error of less than 10%.
- Integrating the attention mechanism enhances the model's ability to capture key features, though it also increases prediction uncertainty compared to models without the attention mechanism.
- This study underscores the necessity of considering both prediction accuracy and uncertainty in model development. The proposed approach provides a promising method for efficient and reliable 3D morphology prediction in geotechnical materials.

References

1. Bowman, E. T., Soga, K., & Drummond, W. (2001). Particle shape characterisation using Fourier descriptor analysis. Géotechnique, 51(6), 545–554.
2. Guida, G., Viggiani, G. M. B., & Casini, F. (2020). Multi-scale morphological descriptors from the fractal analysis of particle contour. Acta Geotechnica, 15(5), 1067–1080.
3. Cavarretta, I., Coop, M., & O'sullivan, C. (2010). The influence of particle characteristics on the behaviour of coarse grained soils. Géotechnique, 60(6), 413–423.

Liu, H., Zhang, Z., Su, H.. 3D characterization of particle morphology in gravel using SFM-MVS photogrammetry, Autom. Constr., under review.
Liu, H., Su, H., Sheil, B. Automatic determination of 3D particle morphology from multi-view images using uncertainty-evaluated deep learning method, Adv. Eng. Inform., under review.
Liu, H., Sun, L., Dias-da-Costa, D.. The use of AI-enhanced computational mechanics in geotechnical engineering, Artif. Intell. Rev., Accepted.