AI-assisted identification, morphological characterisation and quantification of micro- and nanoscale asbestos, microplastic and carbon fibres for human and environmental exposure control

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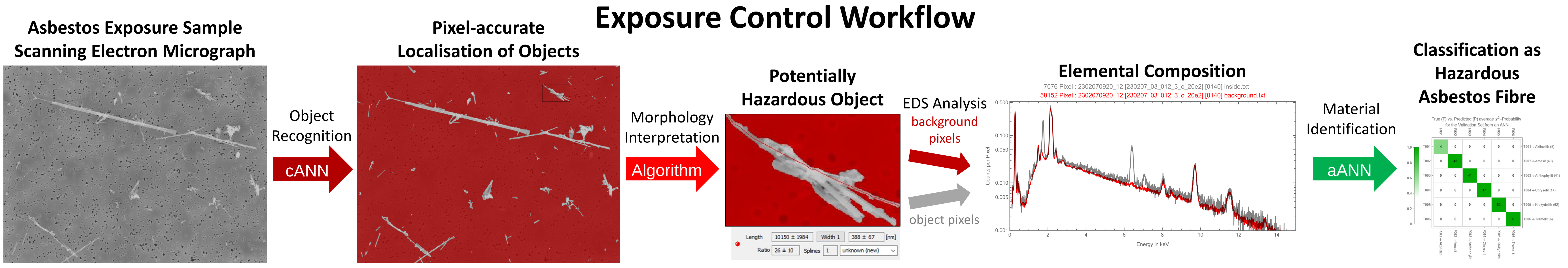
Introduction

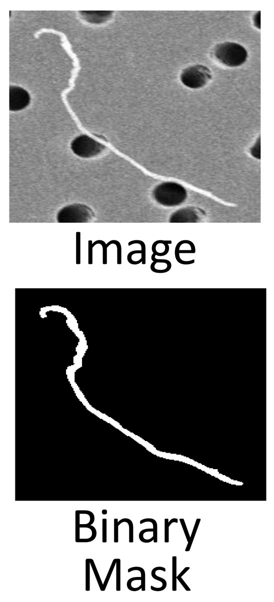
Two classes of artificial neural networks (ANNs) have been deployed to automate the localisation, morphological characterisation, identification and quantification of micro- and nanoscale dust objects being sampled from workplace or environmental atmospheres on filters and automatically imaged by scanning electron microscopy (SEM). Convolutional ANNs (cANNs) were trained on approximately 20 gigapixels of manually annotated digital image data. They localise objects in SEM images with pixel accuracy. A second class of attention mechanism-based ANNs (aANNs) is used to categorise the elemental composition of mineral fibres that were located by the cANN and analysed by energy dispersive X-ray spectroscopy (EDS). These ANNs are currently able to distinguish 75 different minerals, including not only the 6 asbestos materials but also vitreous and rock wool fibres. For microplastics and carbon-based dusts, correlative Raman microscopy provides chemical information for localised fibres and particles. Our aAANs are also being trained to identify such materials. These automated tools will help to reduce the cost and workload for characterising the composition of potentially hazardous atmospheres and aim to implement new measurement techniques for exposure control of asbestos, nanofibres and microplastics.

Exposure Control Workflow



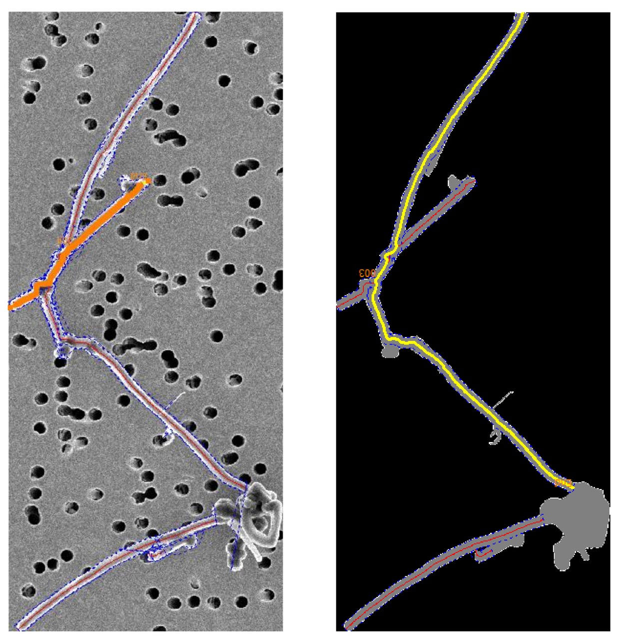
AI for Object Recognition

For object recognition we deployed a cANN based on the U-Net [2] architecture with a ResNet encoder [3]. The U-Net was trained by supervised learning on a data set of more than 1000 manually annotated high-resolution SEM images (20 MPixel) of carbon nanotubes and other fibrous materials. Data augmentation techniques were applied to make our model more robust to fluctuating image acquisition parameters. Using AdamW with a learning rate of 10^{-4}, we optimised a combination of Focal and Dice Loss. When trained for about 2000 epochs, the net achieved an average dice score of 0.94 on a validation data set of 1/8 of the total data.



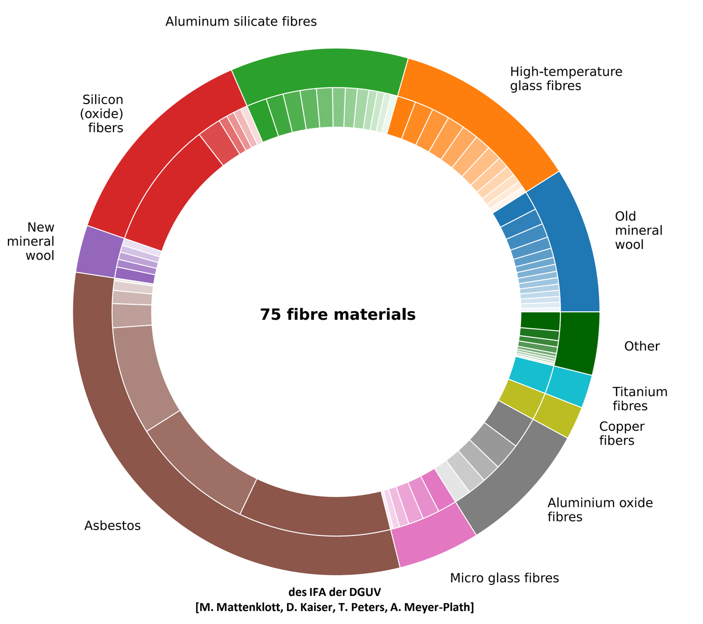
Algorithmic Morphology Assessment

Morphological characteristics are calculated for all objects, including area, Feret diameters, length, curvature, mean width, aspect ration and rectified length. The probable backbones of fibres are traced and intersections are resolved using self-similarity properties of the crossing fibres (diameter, angles, curvature) to decide whether and/or how to connect backbone splines across intersections. This way, individual fibres can be counted and classified for loosely agglomerated fibres.



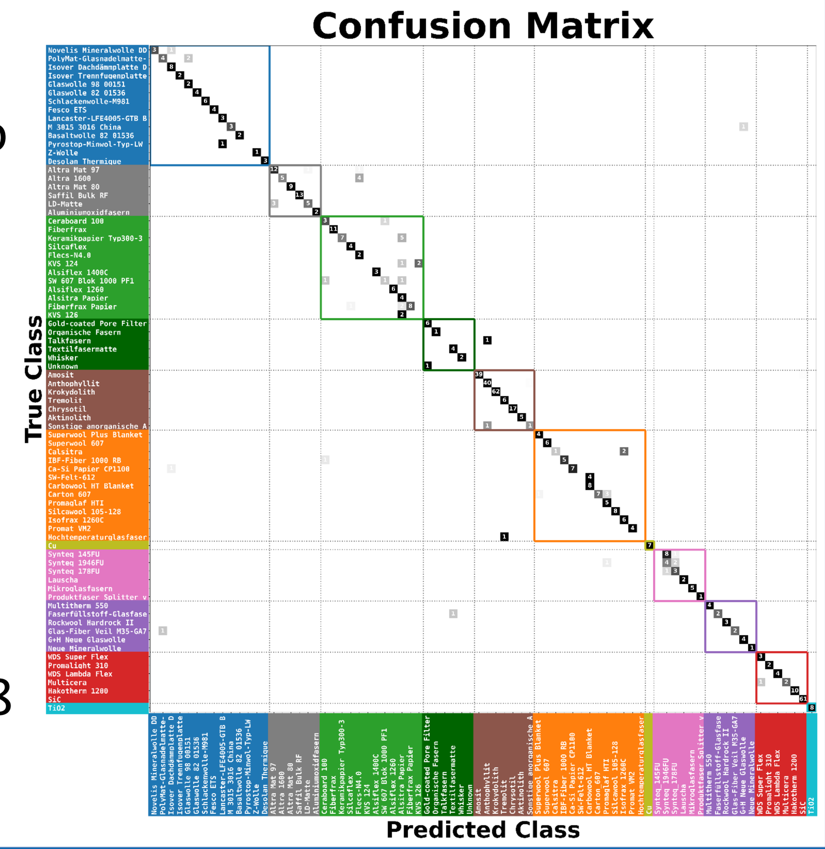
AI for Material Identification

More than 4.000 EDS-spectra acquired from 75 different fibre materials were used to train an aANN consisting of alternating convolutional and multi-head-attention layers [4] using cross-entropy loss.



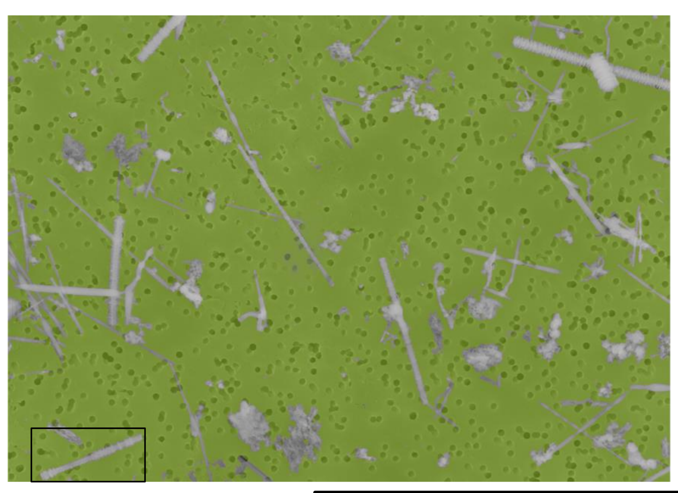
Classes were weighted inversely proportional to their occurrence in the data set.

Our aANN achieves a mean top-1 (top-3) accuracy score of 94,7% (100 %) for the accuracies per material class when validating with 1/8 of the total data.

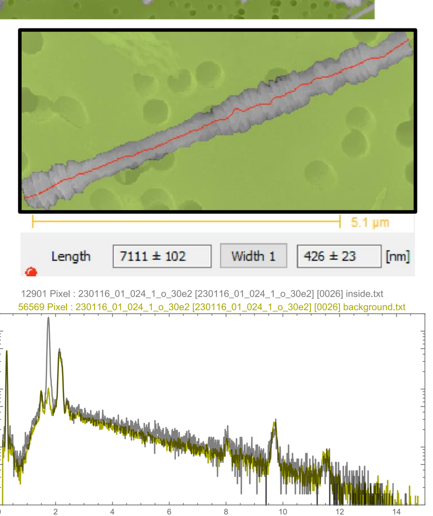


Silicon Carbide Whiskers

SiC whiskers are biodurable nanofibres. A large ensemble was characterised to compile length and diameter statistics. This way, a high content of fibres with respirable shape was identified.

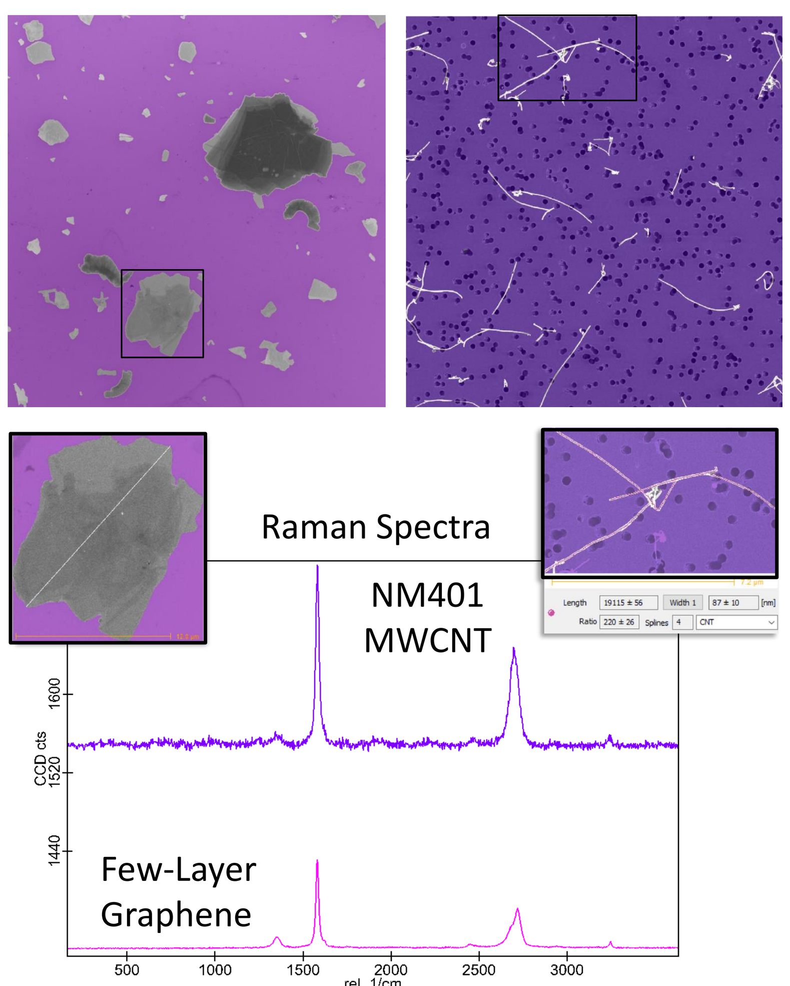


Sample SiC fibre and its automatically acquired EDS-spectrum



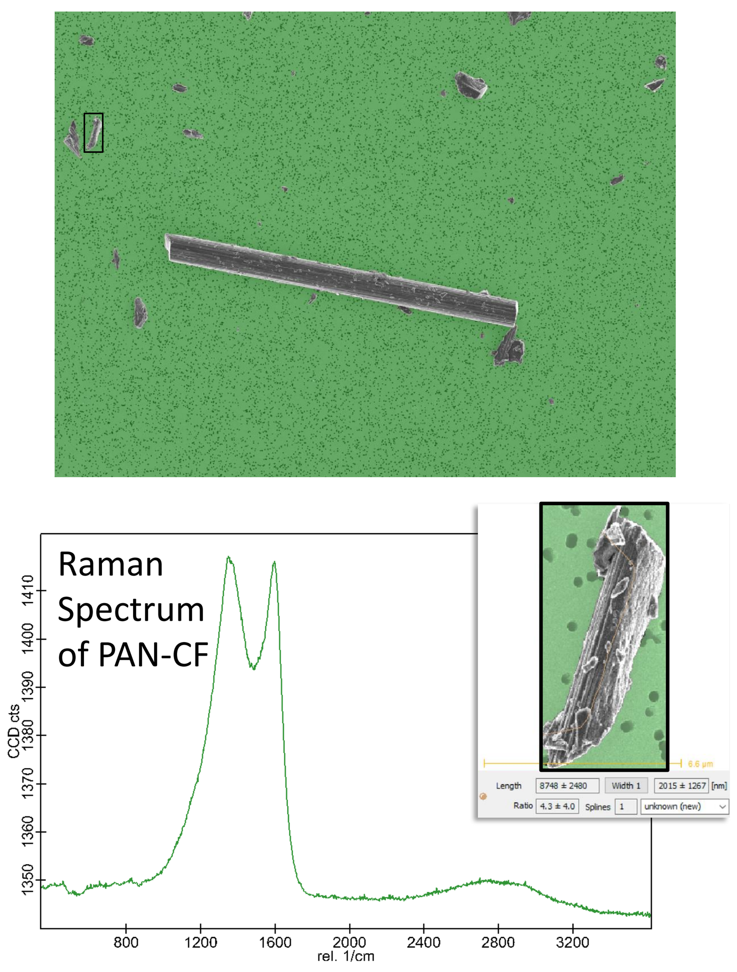
Graphene & Nanotubes

Graphenes and carbon nanotubes (CNTs) are high performance carbon materials. Rigid CNTs exhibit Asbestos-like toxicity. Our automated method allows controlling CNT benchmark exposure limits.



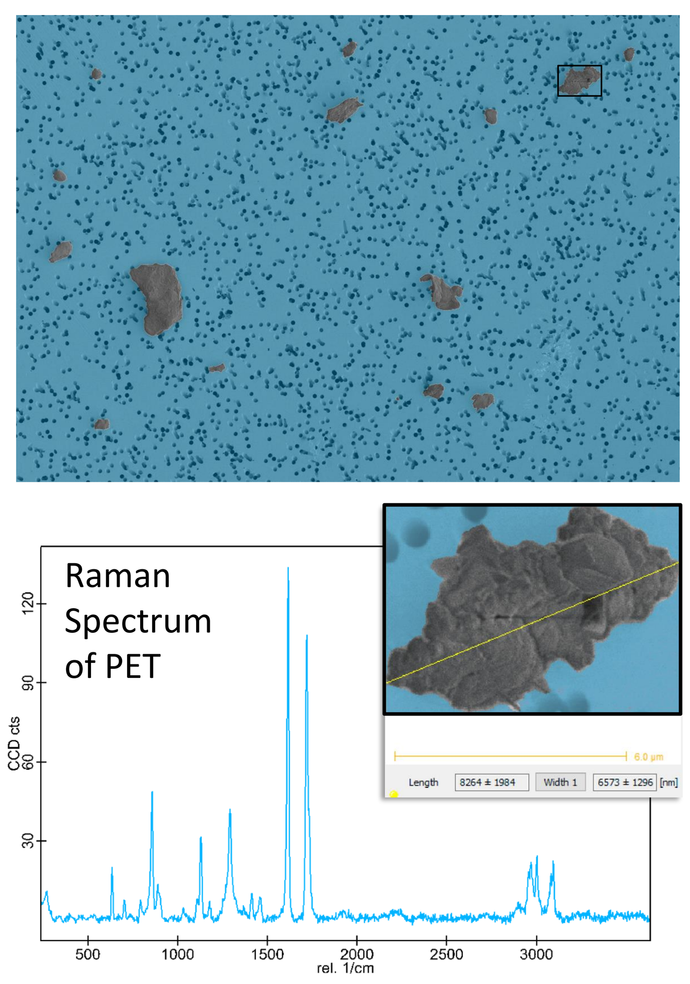
Carbon Fibre Composites

Dust emission during machining of carbon fibre reinforced polymer composites was studied and both, respirable polymer matrix and carbon fibre fragments, were observed.



Microplastics

Dust exposure of pupils in indoor soccer halls with artificial turf at schools was studied using AI-assisted Raman analysis to quantify inhalable and respirable microplastics.



References
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[3] K. He et al. 10.1109/CVPR.2016.90.
[4] Park et al. 10.48550/arXiv.2202.06709