ParticleID—Identification of Particulate Contaminants in Liquids by Neural Network Analysis of Scattering Patterns

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Techniques to identify, measure and count particles in a flow of liquid are becoming widely used in water quality monitoring and industrial process control, but they are still expensive to operate or of low specificity. CSEM is developing a simple, autonomous system to identify particles one-by-one, which harnesses the power of artificial intelligence and needs no extra consumables. The system is based on laser scattering of single particles and classification of the resulting scattering patterns with a purpose-trained neural network.

Natural water contains many particulate contaminations, like bacteria, algae, sand, pollen and micro-plastic particles. These contaminations are tested in regular intervals by water authority bodies to ensure the high standards for drinking water are met. Also in process control it is of high importance to monitor particulate contamination concentrations in process liquids and waste water. In order to identify and quantify particles in a mixed suspension, it is necessary to measure each particle one-by one, or to separate particles by type and size before measuring them as an ensemble. Systems for mixed particle identification currently on the market are complicated and human operated (flow cytometers), of low specificity (particle counters and size analyzers, impedance spectrometers) or targeted to a very special task only (electrochemical monitoring sensors, contamination warning systems).

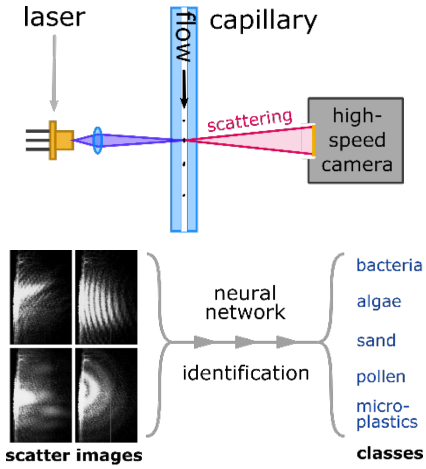

Figure 1: (top) Liquid with suspended particles is run through a narrow capillary. A laser crosses the capillary and produces 2D scattering patterns that are recorded by a high-speed camera. (bottom) The recorded scatter images are analyzed by a neural network to identify the particles, by assigning them to one of the pre-trained classes.

CSEM is working on a new system for autonomous in-line monitoring and counting of multiple particle types in liquids. The system is depicted in Figure 1 top. Liquid containing suspended particles is run through a capillary and a focused laser illuminates the capillary perpendicularly to the flow direction. When a particle crosses the laser beam it scatters some of the laser light and produces a 2D scattering pattern. These patterns are recorded by a high-speed camera and transferred to a PC for identification. A pre-trained artificial neural network (NN) is used to identify the particle class (bacterium, sand, micro-plastic, etc.) automatically (Figure 1 bottom). The beauty of the NN-approach is that it can pick up features from the scattering patterns, and how they change as the particle flows thought the laser light, that cannot be detected with other means. The system can be trained for very specific applications, like monitoring the concentration of particles with a specific size and shape, or counting the number of micro-plastic particles in a mixed sample.

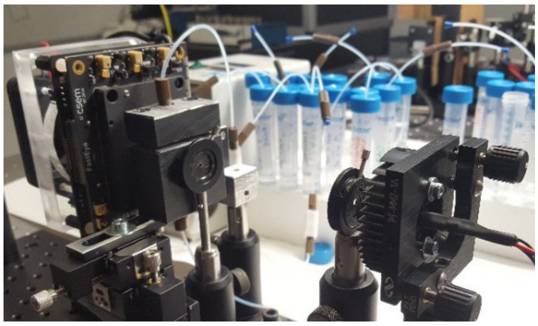

Figure 2: Image of the first prototype setup.

The system currently uses an off-the-shelf capillary and an inexpensive laser diode, together with the "FastEye" high-speed camera developed in-house by CSEM, equipped with an onboard FPGA processor. With this low-cost system (compared to competing products) we could achieve single particle scatter imaging at 2'000 frames per second for particles with diameter 1 to 25 µm. The measurement volume is very small at 0.5 nL and the system was able to analyze liquid at a rate of 200 µL/min. In a measurement campaign we have recorded a training dataset with 1'000 events per class (PS spheres: 1, 2, 4.5, 5, 10 µm diameter; yeast). A subset of these images was used to train the NN, then the NN was used to classify the entire dataset. The scattering events were sorted by intensity of the scattering signal. For events with strongest signal the classification results were very good for each class (91.7% average), and also for weaker events the classification worked very well. The NN was successful in distinguishing 4.5 µm from 5 µm polystyrene spheres, which attest that the system can achieve a size resolution of < 0.5 µm.

One of the target applications is water quality monitoring. We have dissolved baker's yeast in water and measured it with our system. The NN was able to pick out the yeast cells from polystyrene particles of comparable size (4.5, 5 and 10 µm) with remarkably high accuracy of 86% for the strongest events. In addition, we were able to record video sequences of yeast cells as they traversed the laser beam. A rotation of the scattering pattern was visible, indicating that video sequences contain valuable additional information that can be used to better identify particles.

As a next step, it is planned to test this system a much wider selection of particles found in the environment (different bacteria, algae, pollen, river water, micro-plastic) to see how well the system works with natural samples. Furthermore, it is envisaged to embed the NN classification directly on the FPGA of the FastEye camera, thus making the system a truly autonomous intelligent particle monitoring solution, much smaller and cheaper than existing solutions on the market.