A fully convolutional Network to finely detect particles in dense suspensions and to study the viscous resuspension of a bed of settled particles at very low shield number

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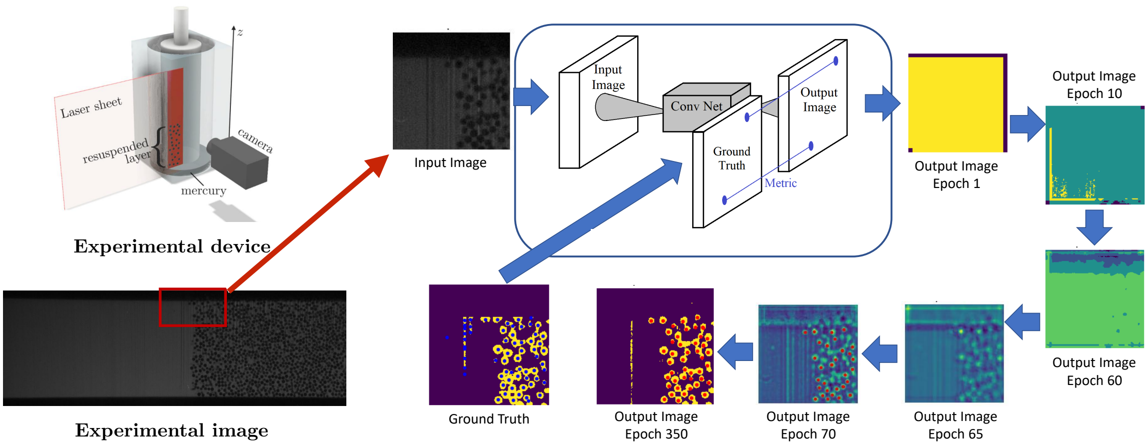

In this PhD, we wish to develop an Artificial Intelligence algorithm based on deep learning techniques to detect with high accuracy the positions and sizes of particles in images of rheology experiments of concentrated suspensions. These particles appear as black disks on a low-contrast background with spatial and temporal illumination inhomogeneities. These illumination issues make it difficult to detect these particles by classical segmentation algorithms and to quantify the detection uncertainties.

To overcome these difficulties, we proposed in a previous work to rely on a convolutional network to perform the particles segmentation. However, this solution requires to have at disposal a significant number of images where the particles are delineated. The originality of our approach was to train the convolutional network on images synthesized artificially using a morphological model. We demonstrated in particular that when trained on these artificial images, the convolutional network had good generalization properties when applied to the experimental images. In this new project, our aim is to foster this approach to quantify the detection errors. The research project that we propose is therefore directly related to two major open problems in computer vision, namely the lack of annotated data, which frequently prevents the use of supervised approaches in images problem related to physical applications, and the quantification of the errors made by the algorithm.

Once the algorithm will be well characterized and trained, we will use it to study the viscous resuspension of a bed of particles previously settled in a flow cell. By applying a very low shear to the particle bed, the concentrations remain very high in the suspension and high precision measurements are required when we seek to quantitatively describe the rheological behaviour of this material. This experiment will allow, for the first time, to characterize the local rheological behaviour of a sheared suspension near the critical concentration for which the viscosity diverges.

Salary : 2500€ per month (brut), scholarship from EUR Spectrum/I3S (Université Côte d'Azur)

Duration : 3 years, starting date : October 2021

Location : Institut de Physique de Nice (Université Côte d'Azur)

Required skills : Master in physics or engineering (or equivalent) with good skills in experimental fluid mechanics and strong interest in machine learning and computer vision.

Keywords : Concentrated suspension, rheology, granular suspension, deep learning, computer vision.

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Key stages of the thesis

Development of the convolutional network detection algorithm (18 months)

- The candidate will get acquainted with the convolutional network algorithm in the Pytorch work environment.
- He will continue the development of the image synthesis algorithm and characterize the important parameters to generate them (average brightness, brightness gradient, noise level, particle density, apparent particle size, particle size distribution, ...).
- He will train the network with as many of the synthetically derived ground truths that are needed to study the relevant parameters.
- The candidate will characterise, for each of the synthesis parameters, the success rate of BlobNet detections using a hand segmented test database as a reference. This study will make it possible to quantify the error in the experimental concentration measurement as a function of local illumination conditions.

Very low Shield resuspension experiments (18 months)

- The candidate will become familiar with the existing experimental device and will make the necessary improvements to it.
- He will carry out measurement campaigns of resuspension at very low Shield number with suspensions of hard spheres.
- He will carry out the data processing.

Supervisors and collaborators :

- Frédéric Blanc (Thesis supervisor) from the Institut de Physique de Nice (UMR7010, Université Côte d'Azur) will be in charge of the resuspension experiments.
- Elie Hachem (Thesis supervisor) from MINES ParisTech will be in charge of the Artificial Intelligence part of the project.
- Bruno Figliuzzi from MINES ParisTech will be in charge of the computer vision and AI part of the project.
- Rudy Valette from MINES ParisTech will contribute to the rheological part of the project.

Project description

One of the activities of the group of suspension rheology of the Institut de Physique de Nice is to carry out measurements of local mechanical quantities of suspensions of very concentrated particles subjected to a shear flow. Two quantities are of particular importance in the characterization of suspension properties: the viscosity field and the concentration field. We access these quantities by taking pictures of the suspension particles during the flow at regular time intervals. The principle of the device that allows us to take these pictures is schematized in figure 1. A very thin flat laser sheet illuminates a transparent suspension and excites the fluorescence of a dye dissolved in the liquid. The fluorescent light is then collected by a camera perpendicular to the laser plane. Figure 2 shows an image obtained with this device. The spherical particles of the suspension appear here as black disks.

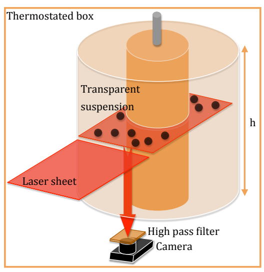

Figure 1: Principle of the image recording device.

The viscosity field is deduced from the velocity field measurement by correlation of successive images. This technique is robust and the results depend little on the quality of the images. The measurement of the concentration field requires the detection and segmentation of the particles present in the image and is much more delicate. We have so far used classical image segmentation algorithms based on morphological transformation tools [1, 2, 3]. However, these are subtle to implement because the variability of the lighting conditions inherent to transparent suspensions obliges to systematically readjust their parameters of use.

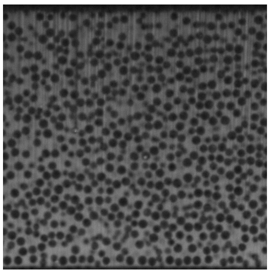

Figure 2: Example of a real image to be processed.

To overcome these difficulties and to be able to detect particles in a completely automated way, we started to develop an image processing algorithm based on a convolutional network (named BlobNet hereafter) [4, 5]. One of the originality of our approach is to train the network not from images of real experiments but from a series of images generated from morphological models (figure 3).

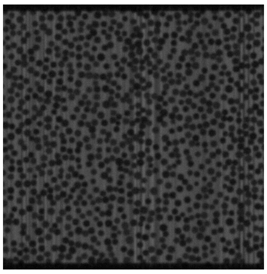

Figure 3: Example of a synthetically generated image.

Such an approach brings an advantage over traditional machine learning techniques. Indeed, like all supervised learning algorithms, convolutional networks require a dataset of annotated experimental images to be trained, referred to as "ground truth". To construct the images of the ground truth, it is necessary to identify manually the objects to be detected, i.e. the positions and sizes of the particles for the subject that concerns us. The annotation is a time consuming task, which renders the use of supervised algorithm difficult in a lot of problems related to physical applications. With our approach of artificial synthesis of the "ground truth", the positions and sizes of the particles are known by construction, which allows us to get rid of the difficulty of obtaining a reliable learning database.

The objective of the thesis is to continue the work already started by characterizing precisely the detection biases of the BlobNet algorithm. The knowledge of these biases is of utmost importance to finely measure the rheological properties of concentrated suspensions. As an example, figure 4 shows radial profiles of particle concentration in the gap of a cylindrical Couette. These profiles, which illustrate the migration phenomenon in sheared suspensions, were measured using BlobNet (orange curve) and a traditional segmentation algorithm (blue curve) [3].

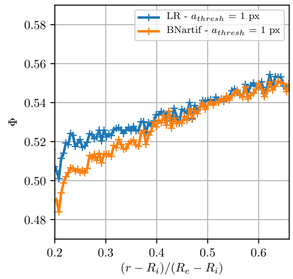

Figure 4: Influence of the detection algorithm on the concentration profiles of a sheared suspension in the gap of a cylindrical Couette. BlobNet (orange) vs classical segmentation (blue).

The discrepancy between these measurements, although subtle, has important consequences on the measurement of rheological properties that we deduce from these profiles. Furthermore, giving a confidence interval for these measurements is extremely tricky because the biases are difficult to quantify, especially for the traditional segmentation algorithm which depends on the slight spatial and temporal variations in brightness inherent to these experiments. The learning process of BlobNet with the help of a synthetic ground truth will allow us to go beyond this difficulty and to get a better understanding of these detection biases. Indeed, by building the training dataset with well controlled parameters (average luminosity, luminosity gradient, noise level, particle density, apparent particle size, particle size distribution, ...) and by determining the detection success rate of BlobNet as a function of these parameters, we will be able to measure the impact of these parameters on the measurement of the local particle density.

Once BlobNet will be well characterized and trained, we will use it to study the viscous resuspension of a non-Brownian particle suspension in a very concentrated regime (figure 5). In such experiments, a bed of negatively buoyant particles is suspended vertically by a shear produced by the rotation of the internal cylinder (rotor). In order to take pictures of the particles, a vertical laser sheet thinner than the particles illuminates the transparent suspension.

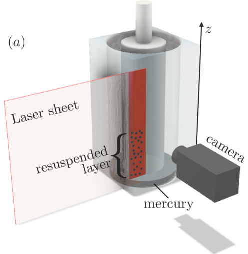

Figure 5: Experimental device for local resuspension measurements [3].

In a previous work, the measurement of the vertical concentration profiles allowed us to deduce the particle normal stresses that develop in the suspension when the suspension is sheared [3]. In this study, we also found an unexpected behavior when the shear stress is very low compared to the apparent weight of the particles (low Shield number). Instead of expanding under the effect of a low shear, the initially sedimented particle bed collapses and the flow is localized near the rotor. In this experiment, the particle concentration is very close to the critical "jamming" concentration for which the suspension viscosity diverges. Close to this jamming concentration, very small differences in concentration have a significant impact on the rheology. At these very high concentrations it is therefore of utmost importance to have at our disposal a powerful and well-characterized measurement tool like BlobNet.

This very low Shield number resuspension experiment is a fundamental rheology study and will follow on from the important work on imposed pressure rheology by Boyer et al [6]. In that study, the authors used an innovative device to shear a suspension (figure 6).

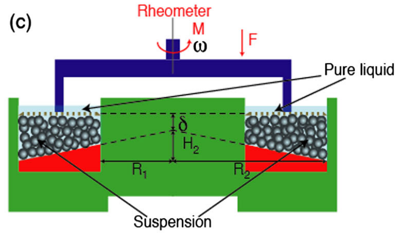

Figure 6: Experimental device for rheology under imposed pressure from Boyer et al. [6].

A grid that acts as a rotor and that can let the suspending fluid pass freely, imposes a particle pressure by pressing on the solid phase. During the shear imposed by the rheometer, the rotor (in blue on figure 6) adapts its vertical position in order to maintain the set pressure. In this imposed pressure experiment, the particle concentration adapts to the rotation speed of the rotor. At low rotational speeds, Boyer et al. explored concentrations very close to the packing concentration, which is extremely difficult with conventional rheology tools.

The proposed resuspension experiment can also be interpreted as an imposed pressure rheology experiment. The pressure is here imposed by gravity and the negative buoyancy of the particles. While to exploit their macroscopic measurements Boyer et al. made the assumptions of a homogeneous suspension, in particular without vertical concentration gradient, and of a uniform shear throughout the flow cell gap, our experiment will allow us to have access to all these data without prior assumptions. The possibility to perform, thanks to BlobNet, fine measurements of the concentration field will allow us to revisit the work of Boyer et al and to bring a more complete vision to this fundamental topic.

References

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