Arbitrary-scale Flow Matching for super-resolution on satellite maritime images

Internship for Master 2 or École d'Ingénieur student

Expected starting: February/March 2025 (6 months)

Keywords

Flow Matching, diffusion models, super-resolution, Sentinel-2, PlanetScope, debris detection, AI for Science

Context and Objectives

Scientific context. More than a thousand satellites are currently orbiting the Earth to acquire images from the Earth's surfaces. Constellations of satellites operated by spatial agencies and governments enable the global monitoring of all land surfaces and oceans. Although these non-commercial satellites provide open-access and free images, their spatial resolutions are often limited, at best around 10 meters.

While these spatial resolutions are enough in various applications, they might be a limited factor for specific applications where fine-grained details need to be detected such as buildings, hedges, or animals. A possible solution to artificially enhance the spatial resolution of images is *super-resolution* (SR). This technique can be framed as an inverse ill-posed problem that consists of learning the inverse of a degradation function that can be applied to a low-spatial resolution (LR) image to estimate a high-spatial resolution (HR) image. The last decade of research in this field has been boosted by the development of learning strategies, in particular deep learning, to learn the degradation function. Recently, diffusion models, a generative approach, have enabled major advances in super-resolution, especially in terms of perceptual visualisation [6].

In the context of remote sensing, super-resolution has also been boosted by recent advances in generative models [9], including diffusion models, with two main concurrent settings used for learning the degradation function. The first consists of training the model using synthetic pairs of satellite images obtained by downsampling the HR image. At inference, the trained model is usually applied to either the HR image to estimate a very high spatial resolution (VHR) image or a real LR image captured by another sensor. In both cases, it creates a domain gap either due to the data distribution change when applying the model to another spatial resolution or the colorimetric change induced by the change of the sensor characteristics. To overcome this domain gap, the second solution consists of employing a cross-sensor setting in which real pairs of images, coming from different sensors, are used to train the super-resolution model. This realistic scenario induces an additional challenge during training as the images might not be correctly co-registered, be captured by sensors having different spectral characteristics, and at different times, creating changes in the observations [5]. There is no consensus in the literature and further work should make it possible to use super-resolution techniques to obtain realistic HR images that preserve the physical content and are not visually pleasing images. Finally, super-resolution models are often tested only with a set of pre-defined reconstruction and perceptual metrics, without showcasing their use in real-world applications.

Objectives of this work. This work aims to address the problem of super-resolution in the challenging context of maritime applications, especially biodiversity monitoring and maritime surveillance. In particular, the objective is to test the impact of super-resolution models for **improving the detection of debris** [2] from low-spatial optical resolution images and **improving the detection of maritime objects such as vessels or ships** [7]. To overcome the difficulty of cross-sensor resolution, we will *(i)* first explore the development of super-resolution methodologies in a traditional super-resolution setting with Flow matching [3, 1] where down-sampled HR images are first used to train the model. We will then *(ii)* study Arbitrary-Scale Super-Resolution techniques [4, 11, 10], which are methods that abstract the resolution of the grid used to define the images through the use of implicit functions. Ultimately, this could be used to focus the super-resolution on specific parts of the image, which is of prime importance in a maritime context where the sea/ocean does not need to be super-resolved for the final task. Finally, we will consider *(iii)* new super-resolution strategies involving gradients of the image by choosing a representation space made of gradients instead of colours. We postulate that this would help reconstruct the fine details of objects. The final reconstruction (in the colour space) is then achieved by solving a Poisson equation, similarly to [8].

Work Planning

To address the aforementioned objectives, a tentative plan is given below.

- Literature review of advanced super-resolution techniques.
- Implementation of flow matching for super-resolution in the gradient space.
- Evaluation of the proposed approach and comparison with state-of-the-art methods for debris detection and maritime object detection.

Candidate Profile

We are looking for a candidate

- who is a Master 2, École d'Ingénieur or equivalent student in computer science or applied mathematics with excellent academic track;
- has a strong background in computer science, machine learning, and/or signal and image processing;
- has excellent programming in Python and is familiar with a deep learning framework, such as PyTorch;
- potentially has experience with remote sensing, or at least a keen interest in the application;
- has excellent communication skills in French or English;
- has a keen interest in research — please note that **there is a funded opportunity to pursue a PhD within the team on this topic**.

Organisation

The master thesis will start around February / March and last for a period of 4 to 6 months. The research will be done at Université Bretagne Sud in Vannes. The expected intern will join the OBELIX research group (`www.irisa.fr/obelix`) from IRISA (UMR 6074) located at the Université Bretagne Sud in Vannes, France. He/She will be jointly supervised by:

- Dr. Charlotte Pelletier[1], Assoc. Professor (Maîtresse de Conférences) UBS/IRISA,
- Dr. Minh-Tan Pham[2], Assoc. Professor (Maître de Conférences) UBS/IRISA,
- Prof. Nicolas Courty[3], Full Professor UBS/IRISA.

This internship is part of the European Horizon AXOLOTL[4] project, for which exchanges with Cypriot researchers are planned.

Application

Send your **CV + Motivation letter + transcripts for the two last years** to

- `charlotte.pelletier@irisa.fr`
- `minh-tan.pham@irisa.fr`
- `nicolas.courty@irisa.fr`

Deadline: **15 December 2024**. Selected candidates will be contacted for interview.

References

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