Proprioception Is All You Need: Terrain Classification for Boreal Forests

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Our Approach

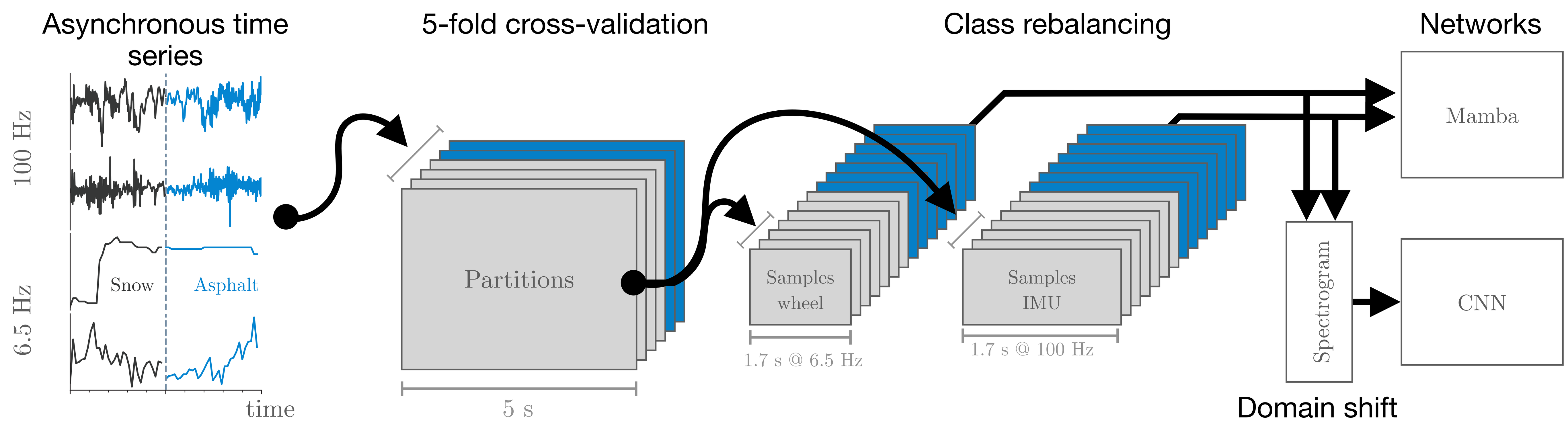

Figure 1: Overview of the training process. From the left, data from asynchronous sensors were recorded and the terrain on which the robot was driven is hand-labeled. To allow a 5-fold cross-validation, trajectories are split into 5 s partitions. Classes are then rebalanced through oversampling before being fed to the different networks. The Convolutional Neural Network (CNN) performed classification on spectrograms, while Mamba classified the samples directly in the time domain.

(a) Silty loam (b) Deep snow (c) Asphalt (d) Flooring (e) Ice

Figure 2: Types of terrains considered in our dataset.

Context & Motivations

- Being one of the largest land biomes on Earth, boreal forests are home to many mobility-impeding terrains that should be negotiated by autonomous vehicles, hence the need to study terrain awareness in this environment.
- Boreal forests challenge conventional exteroceptive-based terrain classification (TC).
  - The **dense coniferous canopies** obstruct the sunlight, yielding low visual feature contrast.
  - **Light is usually scarce in winter**, which hinders the capability of TC methods that rely on light.
  - Both cameras and lidars are influenced by **harsh environmental conditions** such as snowstorms, heavy rain, or fog.
- Proprioceptive sensors have the benefit of providing direct information about the physical characteristics of a surface, through their effect on the dynamics of a uncrewed ground vehicle (UGV).

`BorealTC` dataset

- Recorded with a *Husky* A200 from *Clearpath Robotics* (Kitchener, Ontario, Canada).
- Two kinds of proprioceptive measurements
  - Wheel service (motor currents and wheel velocities) @ 6.5 Hz.
  - Xsens MTi-30 IMU (6-DOF angular velocities and linear accelerations) @ 100 Hz.
- Driven on silty loam, deep snow, asphalt, flooring, and ice.

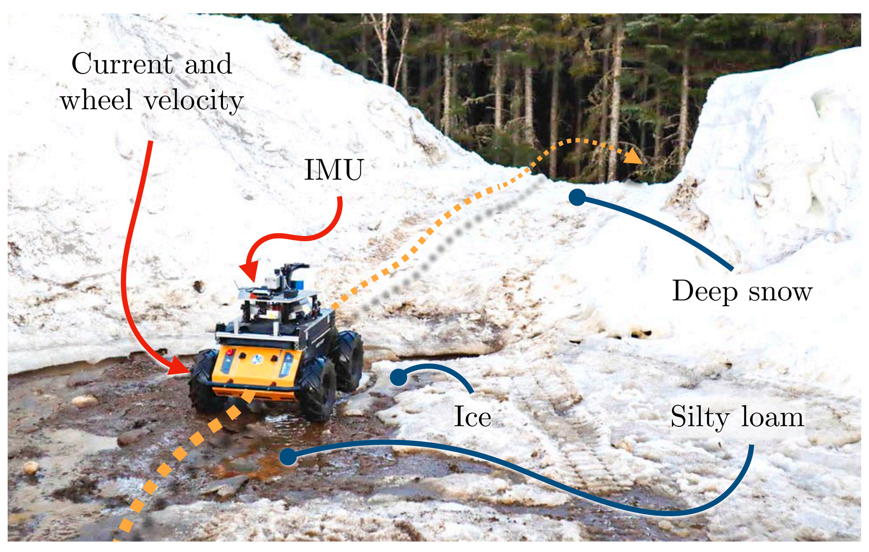

Figure 3: An example of challenges caused by terrain in boreal forests.

Acknowledgments and References

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[1] Fabio Vulpi, Annalisa Milella, Roberto Marani, and Giulio Reina. Recurrent and convolutional neural networks for deep terrain classification by autonomous robots. *Journal of Terramechanics*, 96:119–131, August 2021.

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Impact of train dataset size on model performance

On a combination of our `BorealTC` dataset with the `Vulpi` dataset [1].

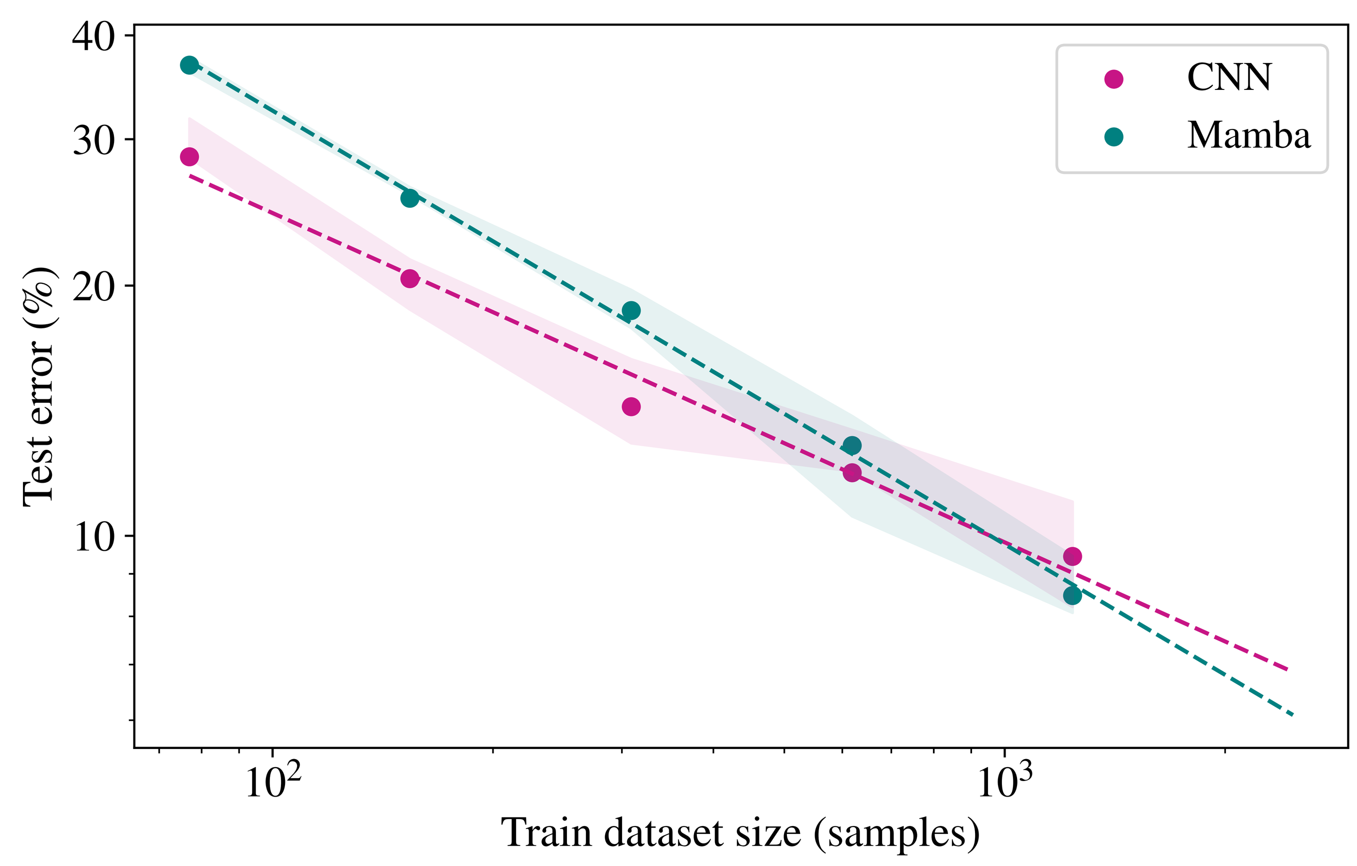

Figure 4: Influence of train dataset size on the test error in log-log scale. Performance was assessed by combining `Vulpi–BorealTC`. Bands show the interquartile range (IQR) over 5 folds.

Limitation of hand-made labels

We compared the latent space of both datasets (`BorealTC` and `Vulpi` [1]) with a t-distributed stochastic neighbor embedding (t-SNE). The embeddings of a terrain are clustered with other terrains of similar properties.

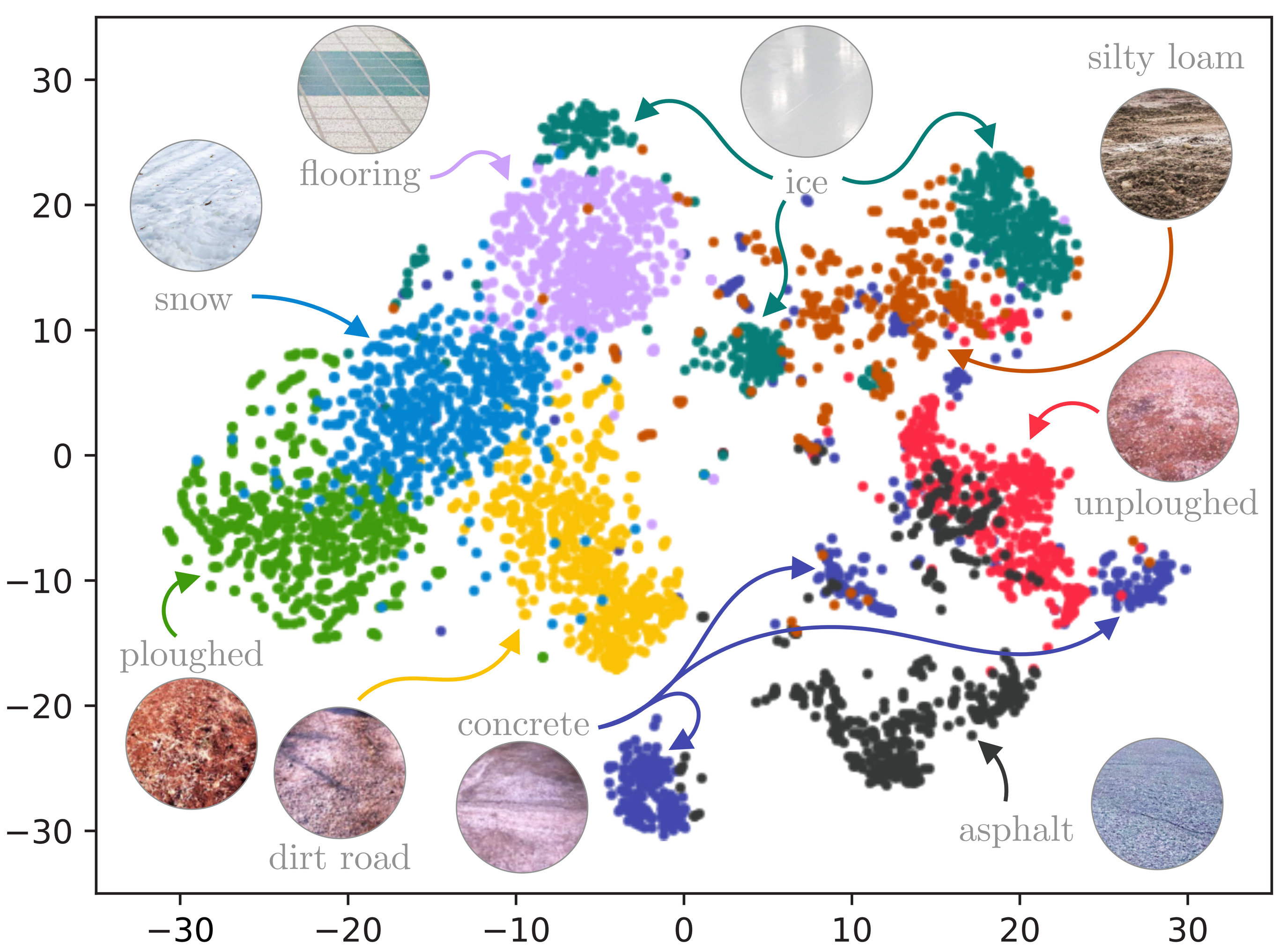

Figure 5: An illustration of class proximity using t-SNE analysis from our CNN classifier trained on both datasets. Each colored dot represents an embedding for a given class. Each inset illustrates a terrain class in a dataset.

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