

# Chapter 1

## Implementation

This section talks in detail about the implementation of the framework. We will first talk about from the utilized robot, then describe each step in the dataset generation, illustrate the utilized estimators and finish by listing the employed software.

### 1.1 Robot

We tested our framework on a legged crocodile-like robot called *Krock* developed at EPFL. The next figure shows the robot in real life with a coat and in a simulated environment.



(a) Krock in real life.

(b) Krock in the simulator.

Figure 1.1. *Krock*

*Krock* robot was created for the purpose of monitoring real crocodiles, hence it must walk and behave realistically enough to fool the real crocodiles. *Krock* has four legs, each one of them is equipped with three motors in order to rotate in each axis. The robot can raise itself in three different configurations, gaits, using the four motors on the body connected to the legs. In addition, there are another set of two motors in the inner body part to increase *Krock*'s move set. The tail is composed by another set of three motors and can be used to perform a wide array of tasks. The

robot is 85cm long, weights around 1.4kg and in its standard gait configuration its distance from the ground is 16cm. The next figure 1.2 shows *Krock* from the top helping the reader understanding its composition and the correct ratio between its parts. Also, each motor is highlighted with a red marker. *Krock*'s moves by lifting and moving forward one leg after the other. The following

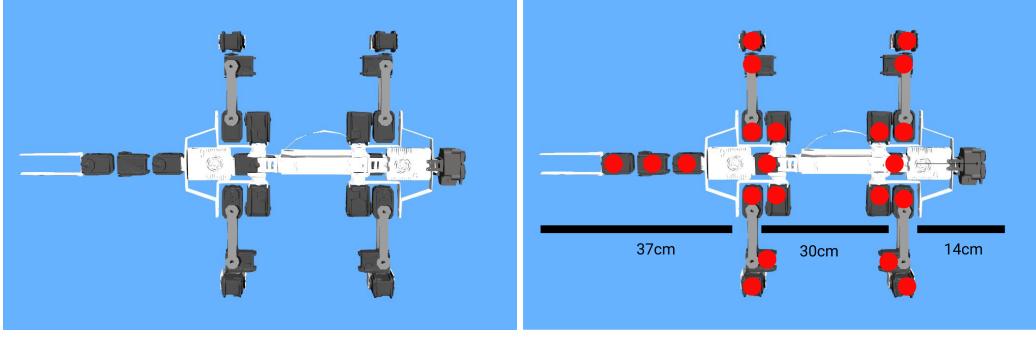
(a) Top view of *Krock*(b) Details highlighted in *Krock*

Figure 1.2

figure shows the robots going forward. In our framework we fixed the gait configuration to normal,

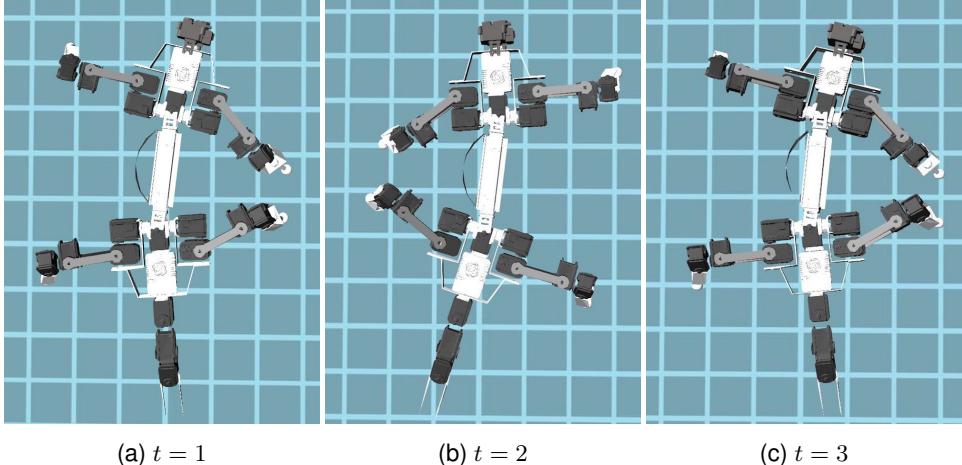


Figure 1.3. *Krock* moving forward. In this gait configuration, the robot distance from the ground is 16cm.

showed in figure ??, where the body is at the same legs' motors height.

## 1.2 Data Gathering

This section describe in detail how we created, collected and processed the synthetic dataset used to train the traversability estimator in supervised way.

### 1.2.1 Heightmap generation

To collect the data through simulation we first need to generate meaningful terrain to be explored by the robot. Each map is stored as a 2D image where each pixel's value represents the terrain's height. For example, the following image shows an heightmap representing a real world quarry and the relative terrain. We created thirty maps of  $513 \times 513$  pixel with a resolution of  $0.02\text{cm/pixel}$

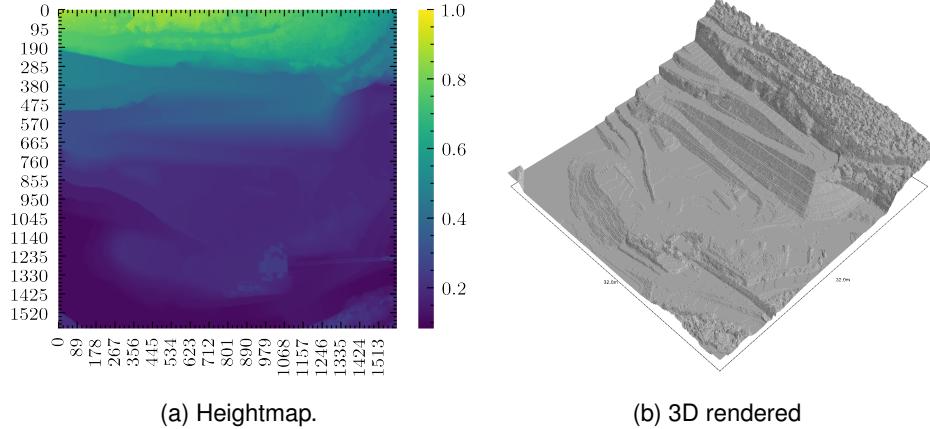


Figure 1.4. This image shows an heightmap and the 3D render of a quarry.

in order to represent a  $10 \times 10\text{m}$  terrain using 2D simplex noise ?. Simplex noise is a variant of Perlin noise ?, a widely used technique in the terrain generation litterature. We divide the maps into five main categories of terrains to cluster differents ground features: *bumps*, *rails*, *steps*, *slopes/ramps* and *holes*. For some map we add three different rocky texture to create more complicated situations, all the maps configuration are shown in detail in table ??.

**Bumps:** We generated four different maps with increasing bumps' height using simplex noise.

**Bars:** In these maps there are wall with different shapes and heights. In

**Rails:** Flat grounds with slots.

**Steps:** These are maps with various steps at increasing distance and frequency.

**Slopes/Ramps:** Maps composed by uneven terrain scaled by different height factors from 3 to 5 used to include samples where *Krock* has to climb.

**Holes** We also included a map with holes

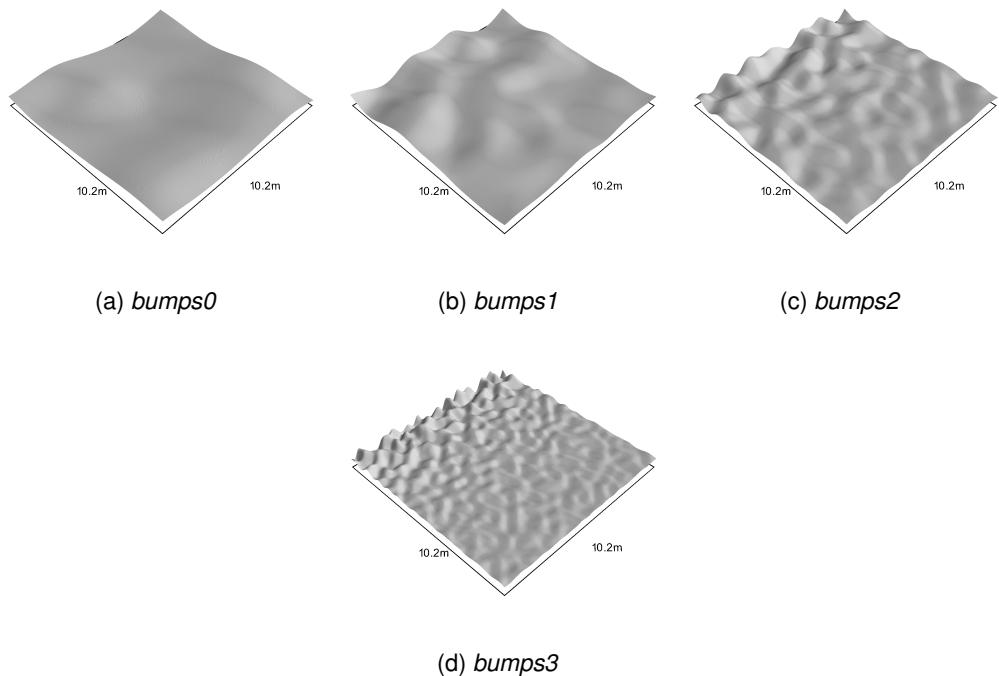


Figure 1.5. Bumps maps ( $10 \times 10\text{m}$ ).

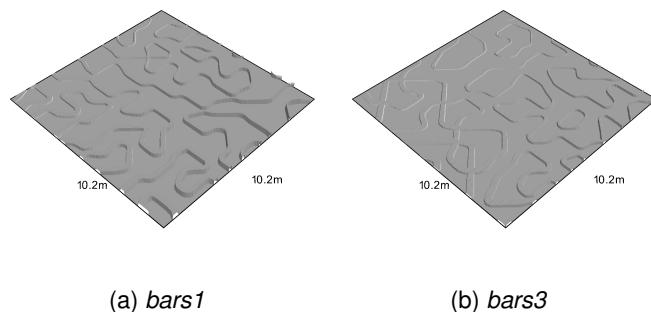


Figure 1.6. Bars maps ( $10 \times 10\text{m}$ ).

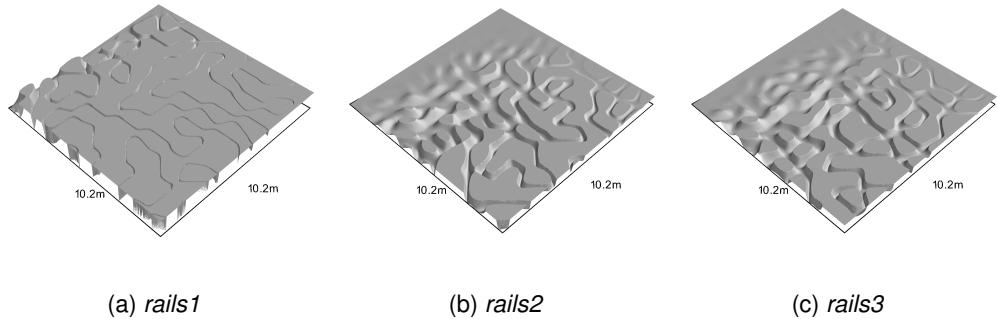


Figure 1.7. Rails maps (10 × 10m).

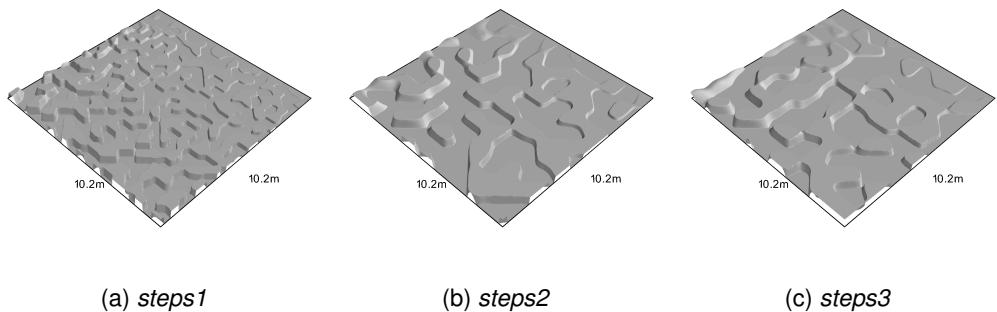


Figure 1.8. Steps maps (10 × 10m).

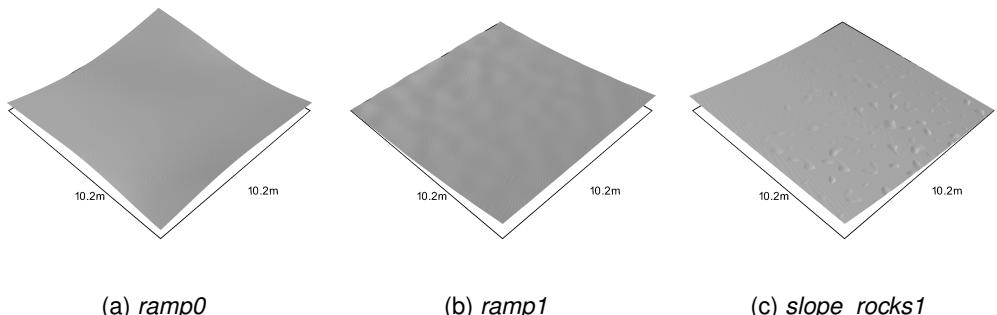
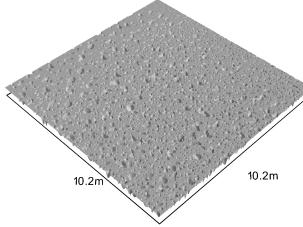


Figure 1.9. Slopes maps (10 × 10m).

(a) *holes1*Figure 1.10. Holes map ( $10 \times 10\text{m}$ ).

### 1.2.2 Simulator

We used Webots as the simulation platform for the robot model and the generated terrain. The controller was implemented using the Robotic Operating System, and send data using a special nodes called topics. The controller implements a ROS' node to publish Krock status including its pose at a rate of 250hz. We decided to reduce it to 50hz by using ROS build it `throttle` command. To load the map into the simulator, we first had to convert it to Webots's `.wbt` file. Unfortunately, the simulator lacks support for heightmaps so we had to use a script to read the image and perform the conversion.

To communicate with the simulator, Webots exposes a wide number of ROS services, similar to HTTP endpoints, with which we can communicate. The client can use the services to get the value of a field of a Webots' Node, for example, if we want to get the terrain height, we have to ask for the field value `height` from `TERRAIN` node. In addition, to call one service, we first have to get the correct type of message we wish to send and then we can call it. We decided to implement a little library called `webots2ros` to hide all the complexity needed to fetch a field value from a node.

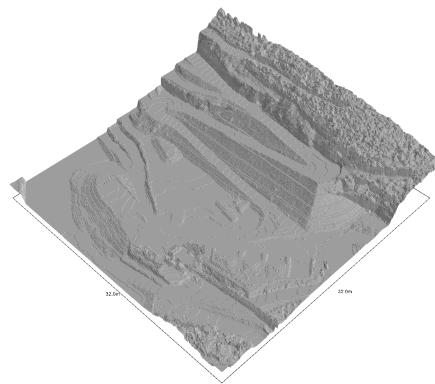
We also implement one additional library called `Agent` to create reusable robot's interfaces independent from the simulator. The package supports callbacks that can be attached to each agent adding additional features such as storing its interaction. Finally, we used `Gym` ?, a toolkit to develop and evaluate reinforcement learning algorithms, to define our environment. Due to the library's popularity, the code can easily be shared with other researches or we may directly experiment with already made RL algorithm in the future without changing the underlying infrastructure.

### 1.2.3 Real world maps

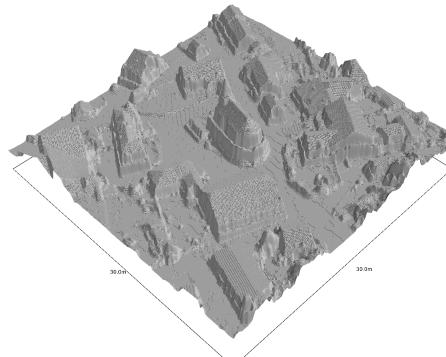
To later evaluate the model's performance, we decide to use real world terrain. We gather two heightmaps produced by ground mapping flying drones from sensefly's dataset, a quarry and a small village. Figure 1.11 shows the original and a 3D render of the heightmap for each terrain

## 1.3 Simulation

To collect *Krock*'s interaction with the environment, we spawn the robot on the ground and let it move forward for  $t$  seconds. We repeat this process  $n$  times per each map. Unfortunately, spawning



(a) Quarry



(b) A small village.

Figure 1.11. Real world maps obtained from sensefly’s dataset. The left images shows the real world location while on the right a render in 3D of the coresponding heightmaps. Both images have a maximum height of 10m.

the robot is not a trivial task. In certain maps, for instance, *bars1*, a map with tons of walls, we must avoid spawning Krock on an obstacle otherwise the run will be ruined by *Krock* getting stuck at the beginning introducing noise in the dataset. To solve the problem, we defined two spawn strategies, a random spawn and a flat ground spawn strategy. The first one is used in most of the maps without big obstacles such as *slope\_rocks*. This strategy just spawn the robot on random position and rotation. While, the flat ground strategy is first selects suitable spawn positions by using a sliding window on the heightmap of size equal Krock's footprint and check if the mean pixel value is lower than a small threshold. If so, we store the center coordinates of the patch as a candidate spawning point. Intuitively, if a patch is flat then its mean value will be close to zero. Since there may be more flat spawning positions than simulations needed, we have to reduce the size of the candidate points. To maintain the correct distribution on the map to avoid spawning the robot always in the same cloud of points, we used K-Means with  $k$  clusters where  $k$  is equal to the number of simulations we wish to run. By clustering, we guarantee to cover all region of the map removing any bias. The following picture shows this strategy on *bars1*. The following table shows

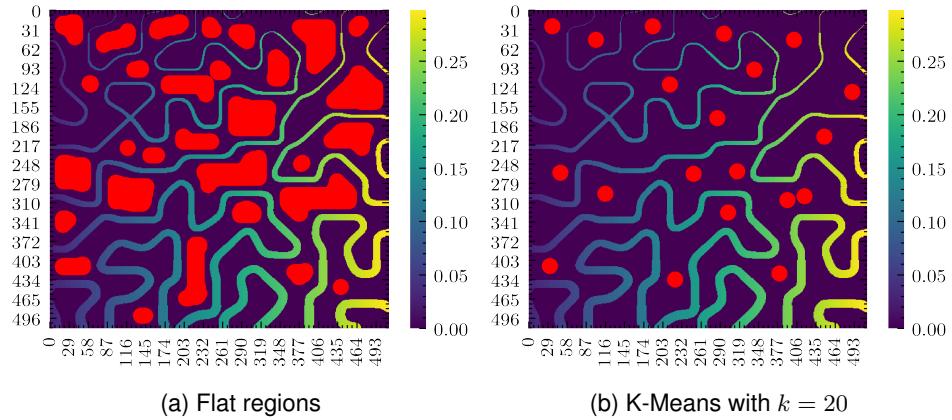


Figure 1.12. Examples of the spawning selection process (marked as red blobs) for the map *bars1*

the maps configuration used in the simulator.

## 1.4 Postprocessing

After the run Krock on each map, we need to extract the patches for each stored pose  $p_i$  and compute the advancement for a given time window,  $\Delta t$ .

### 1.4.1 Parse stored data

First, we turn each *.bag* file into a pandas dataframe and cache them into *.csv* files. We used *rosbag\_pandas*, an open source library we ported to python3, to perform the conversion. Then, we load the dataframes with the respective heightmaps and start the data cleaning process. We remove the rows corresponding to the first second of the simulation time to account for the robot spawning time. Then we eliminate all the entries where the *Krock* pose was near the edges of a map, we used a threshold of 22 pixels since we notice *Krock* getting stuck in the borders of the terrain

Map	Height(m)	Spawn	Texture	Simulations	max time(s)
<i>bumps0</i>	2	random	-	-	-
			rocks1	50	10
<i>bumps1</i>	1	random	-	-	-
			rocks1	50	10
<i>bumps2</i>	1	random	-	50	10
			rocks2	-	-
<i>bumps3</i>	1	random	-	-	-
			rocks1	50	10
<i>steps1</i>	1	random	-	50	10
<i>steps2</i>	1	flat	-	50	10
<i>steps3</i>	1	random	-	50	10
<i>rails1</i>	1	flat	-	50	20
<i>rails2</i>	1		flat	-	10
<i>rails3</i>	1		flat	-	10
<i>bars1</i>	1	flat	-	50	10
	2		-	-	-
<i>bars3</i>	1	flat	-	-	-
<i>ramp0</i>	1	random	rocks1	50	10
			rocks2	50	-
<i>ramp1</i>	3	random	-	-	-
			-	50	10
<i>slope_rocks1</i>	4	random	-	-	-
			-	50	10
<i>holes1</i>	1	random	-	-	-
			-	50	10
<i>quarry</i>	10	random	-	50	10
Total: 1600					

Table 1.1. Maps configuration used in the simulator.

during a simulation. After cleaning the data, we convert *Krock* quaternion rotation to Euler notation using the `tf` package from ROS. Then, we extract the sin and cos from the Euler orientation last component and store them in a column. Before caching again the resulting dataframes into `.csv` files, we convert the robot's position into heightmap's coordinates that are used later to crop the correct region of the map.

To compute the robot's advancement in a time window  $\Delta t$  we look for each stored pose  $p_t$ , in the future,  $p_{t+\Delta t}$ , and see how far it went. The correct value of  $\Delta t$  is crucial. We want a time window small enough to avoid smoothing too much the advancement and making obstacle traversal, and big enough to include the full legs motion. We empirically set  $\Delta t = 2$  since it allows *Krock* to move both its legs and does not flatten the advancement too much.

### 1.4.2 Extract patches

Each patch must contain both *Krock*'s footprint, to include the situations where the obstacle is under the robot, and certain amount of ground region in front of it. Intuitively, we want to include in each patch the correct amount of future informations according to the selected time window. Thus, we should add the maximum possible ground that *Krock* could traverse.

To find out the correct value, we must compute the maximum advancement on a flat ground for the  $\Delta t$  and use it to calculate the final size of the patch. We compute it by running some simulations of *Krock* on flat ground and averaging the advancement getting a value of 71cm in our  $\Delta t = 2$ s.

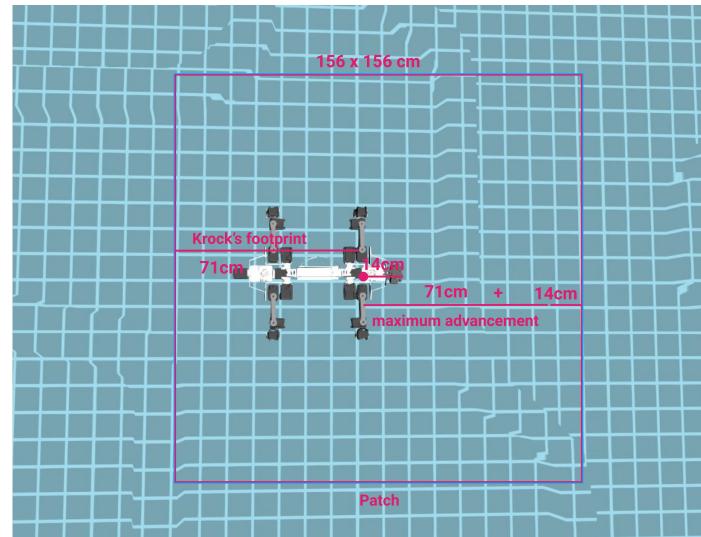
Each patch must include *Krock*'s footprint and the maximum possible distance it can travel is a  $\Delta t$ . So, since *Krock*'s pose was stored from IMU located in the juncture between the head and the legs, we have to crop from behind its length, 85cm minus the offset between the IMU and the head, 14cm. Then, we have to take 71cm, the maximum advancement with a  $\Delta t = 2$ s plus the removed offset. The following figure visualizes the patch extraction process. Lastly, we create a final dataframe containing the map coordinates, the advancement, and the patches paths for each simulation and store them to disk as `.csv` files.

The whole pipeline takes less than one hour to run the first time with 16 threads, and, once it is cached, less than fifteen minutes to extract all the patches. In total, we created almost half a million images.

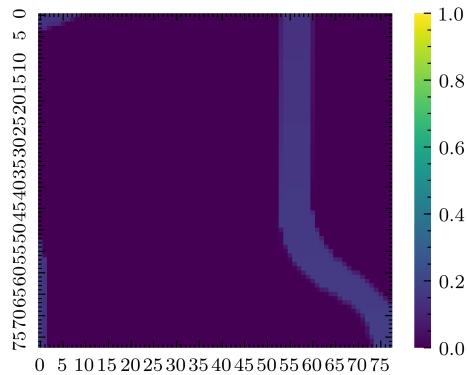
Once we extract the patches, we can always re-compute the advancement without re-running the whole pipeline. The next figure shows the proposed pipeline. The following figure shows the mean advancement across all the maps used to train the model in a range of  $\pm 0.70$ cm, the maximum advancement the used time window,  $\Delta t = 2$ s. As sanity check, we visualized some of the patches from the train set ordered by advancement, to conclude the data generation process was correct. Figure 1.16 shows a sample of forty patches. All the handles used to postprocess the data are available as a python package. Also, we create an easy to use API called `pipeline` to define a cascade stream of function that is applied one after the other using a multi-thread queue to speed-up the process.

### 1.4.3 Label patches

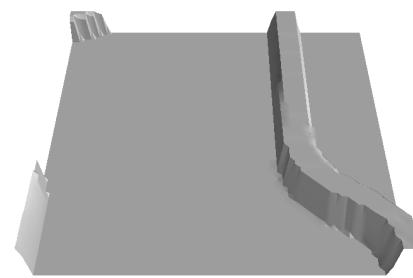
To decide whether a patch is traversable or not traversable we need to decide a *threshold*,  $tr$ , such as if a patch has an advancement major than  $tr$  it is labeled as traversable and viceversa. Formally, a patch  $p_i$  is labeled as *not traversable* if the advancement in a given time window  $\Delta t = 2$  is less than the threshold  $tr_{\Delta t=n}$



(a) Robot in the simulator.



(b) Cropped patch in 2d.



(c) Cropped patch in 3d.

Figure 1.13. Patch extraction process for  $\Delta t = 2\text{s}$ .

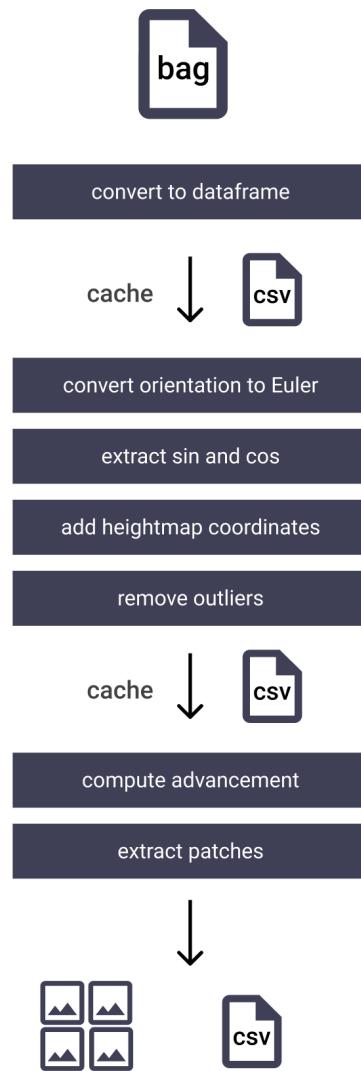


Figure 1.14. Postprocessing Pipeline flow graph, starting from the top.

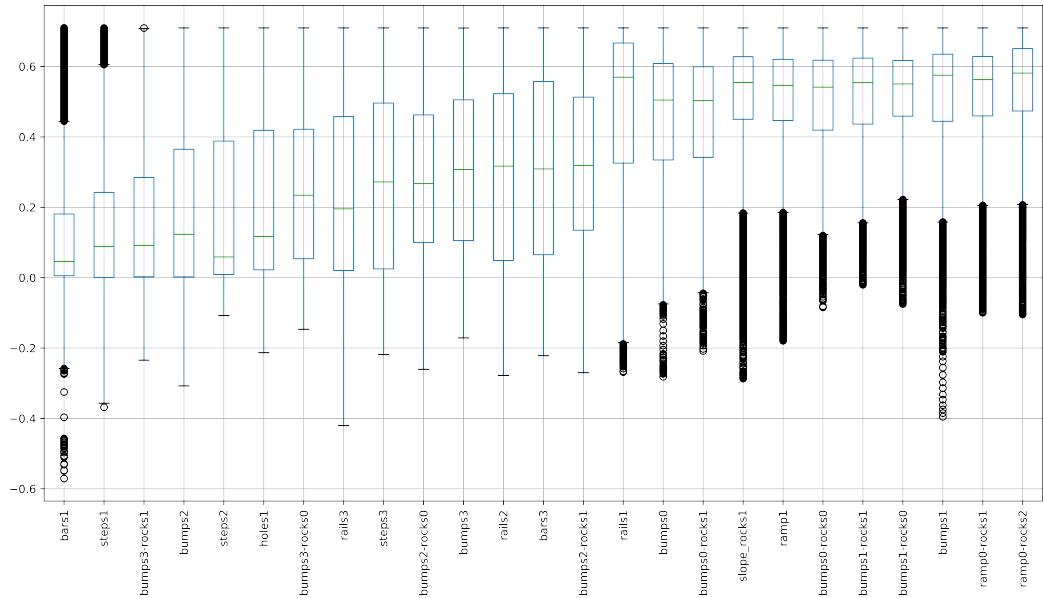


Figure 1.15. Advancement on each map with a  $\Delta t = 2\text{s}$  in ascendent order.

Ideally, the threshold should be small enough to include as few as possible false positives and big enough to cover all the cases where Krock gets stuck. We empirically compute the threshold's value by spawning Krock in front of a bump and a ramp and let it walk.

**Bumps** We spawned the robot on the *bumps3* map close to the end and let it go for 20 seconds. Figure ?? shows Krock in the simulated environment.

Due to its characteristic locomotion, Krock tries to overcome the obstacle using its legs to move itself to the top but it fell backs producing a spiky advancement where first it is positive and then negative. Figure 1.18 shows the advancemetn on this map with  $\Delta t = 2$ , we can notice the noisy output.

A wheel robot, on the other hand, will not produce such graph since it cannot free itself easily from an obstacle. Image a wheel robot moving forward, once it hits an obstacle it stops moving, if we plot its advancement in this situation it will look more like a step than a series of spikes.

**Ramps** The threshold should be small enough to not create any false positive, patches that are traversable but were classified as not. So, we let the robot walk up hill on the *slope\_rocks1* map with a height scaling factor set to 5. We knew from empirical experiment that the robot is able to climb this steep ramp, the advancement is showed in figure 1.19. The mean  $\approx 0.4\text{cm}$  over a  $\Delta t = 2$ , an impressive value considering the steepest of the surface. We can use this information combined with the previous experiment to choose a threshold that is between the upper bound of *bumps* and between the lower bound of *slope\_rocks1*. This will ensure to minimize the false positive. A good value is  $tr_{\Delta t=2s} = 20\text{cm}$ .

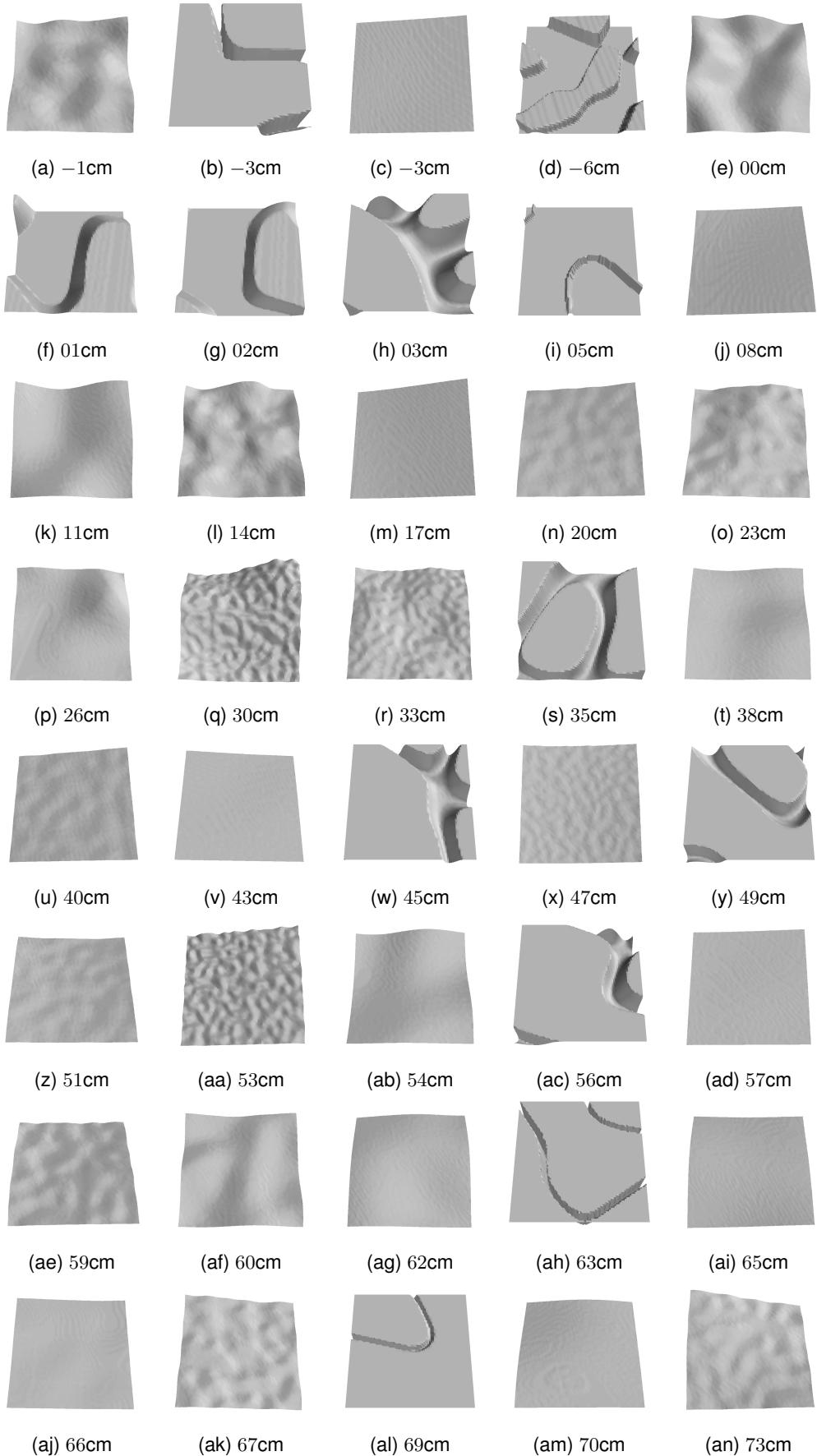


Figure 1.16. Sample of extracted patches from the train set ordered by advancement. The first patches have mostly obstacle close to the robot's head, while the latter have smoother surfaces.

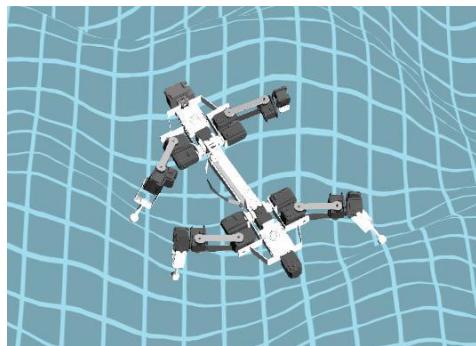


Figure 1.17. Krock tries to overcome an obstacle in the *bumps3* map.

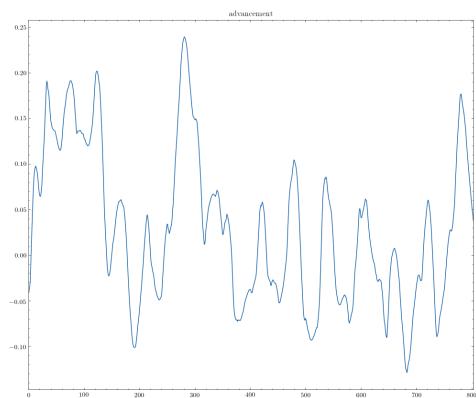


Figure 1.18. Advancement over time with  $\Delta t = 2$  on *bumps3*.

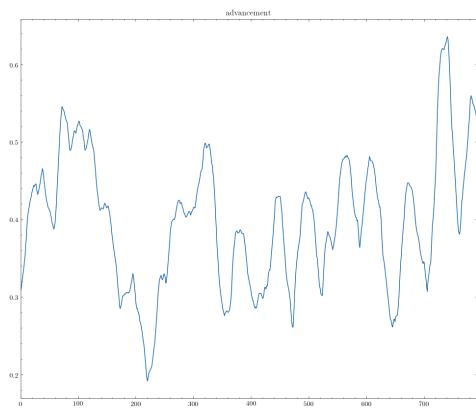


Figure 1.19. Advancement over time with  $\Delta t = 2s$  on *slope\_rocks3*.

## 1.5 Estimator

In this section we described the choices behind the evaluated network architectures.

### 1.5.1 Vanilla Model

The original model proposed by Chavez-Garcia et all ? is a CNN composed by a two  $3 \times 3$  convolution layer with 5 filters;  $2 \times 2$  Max-Pooling layer;  $3 \times 3$  convolution layer with 5 filters; a fully connected layer with 128 outputs neurons and a fully connected layers with two neurons. Figure 1.20 visualizes the architecture.

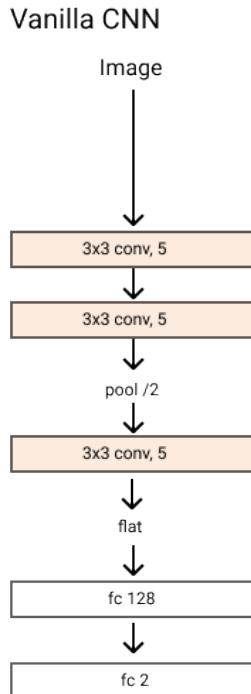


Figure 1.20. Vanilla model proposed by Chavez-Garcia et al. ?. The rectangle represent the building block of each layer. Convolutiol layers are described by the kernel size, the number of filters and the stride.

### 1.5.2 ResNet

We adopt a Residual Network, ResNet ?, variant. Residual networks are deep convolutional networks consisting of many stacked Residual Units : Intuitively, the residual unit allows the input of a layer to contribute to the next layer's input by being added to the current layer's output. Due to possible different features dimension, the input must go through and identify map to make the addition possible. This allows a stronger gradient flows and mitigates the degradation problem. A Residual Units is composed by a two  $3 \times 3$  Convolution, Batchnorm ? and a Relu blocks. Formally

defined as:

$$\mathbf{y} = \mathcal{F}(\mathbf{x}, \{W_i\}) + h(\mathbf{x}) \quad (1.1)$$

Where,  $x$  and  $y$  are the input and output vector of the layers considered. The function  $\mathcal{F}(\mathbf{x}, \{W_i\})$  is the residual mapping to be learned and  $h$  is the identity mapping. The next figure visualises the equation. When the input and output shapes mismatch, the *identity map* is applied to the input as

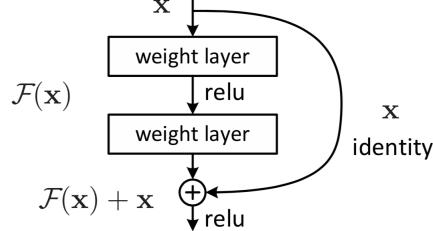


Figure 1.21. Resnet block ?

a  $3 \times 3$  Convolution with a stride of 2 to mimic the polling operator. A single block is composed by a  $3 \times 3$  Convolution, Batchnorm and a ReLU activation function.

### 1.5.3 Preactivation

Following the recent work of He et al. ?, we adopted *pre-activation* in each block. *Pre-activation* works by just reversing the order of the operations in a block.

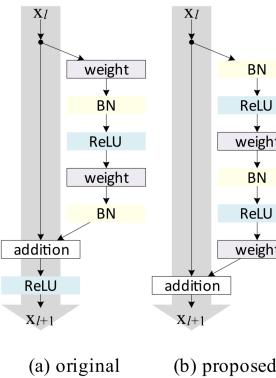
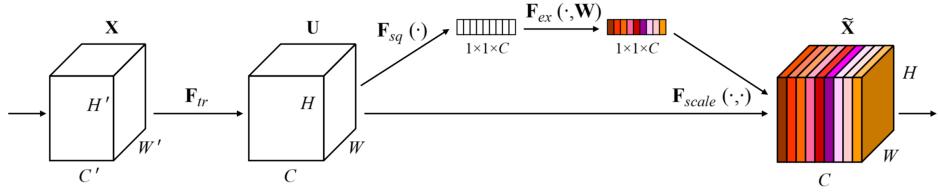


Figure 1.22. Preactivation ?

### 1.5.4 Squeeze and Excitation

Finally, we also used the *Squeeze and Excitation* (SE) module ?. It is a form of attention that weights the channel of each convolutional operation by learnable scaling factors. Formally, for a given transformation, e.g. Convolution, defined as  $F_{tr} : \mathbf{X} \mapsto \mathbf{U}$ ,  $\mathbf{X} \in \mathbb{R}^{H' \times W' \times C'}$ ,  $\mathbf{U} \in \mathbb{R}^{H \times W \times C}$ , the SE module first squeeze the information by using average pooling,  $F_{sq}$ , then it excites them using learnable weights,  $F_{ex}$  and finally, adaptive recalibration is performed,  $F_{scale}$ . The next figure visualises the SE module.

Figure 1.23. *Squeeze and Excitation ?*

### 1.5.5 MicroResNet

The proposed network's architecture is composed by  $n$  ResNet blocks and channel incrementing factor of 2. Originally, ResNet was used to classify RGB images with  $224 \times 224$  pixels and used an aggressive convolution and max-polling operation in the first layer to reduce the images's size. We decided to adopt a less aggressive convolution motivated by the smaller size of our inputs. We tested two kernel sized:  $7 \times 7$  and  $3 \times 3$  with stride of 2 and 1 respectively. Lastly, we used LeakyReLU ? with a negative slope of 0.1 instead of ReLU to allow a better gradient flow during backpropagation. LeakyRelu is defined as follows

$$\text{LeakyRelu}(x) = \begin{cases} x & \text{if } x > 0 \\ 0.1x & \text{otherwise} \end{cases} \quad (1.2)$$

We called this model architecture *MicroResNet*. We proposed four networks layouts: with  $n = 1$  and two fist layers setups,  $3 \times 3$  stride = 1 and  $7 \times 7$ , with and without the Squeeze and Excitation module. Those architectures can be used both for regression and classification by only chaning the output size of the fully connected later, 2 for classification and 1 for regression. All others layers are equals. Figure 1.24 add additional informations. Our models have approximately 35 times less parameters than the smalles ResNet model, ResNet18 ?, that has 11M parameters. To simplicity we used the following notation to describe each architecture variant: MicroResNet-3x3/7x7-/SE.

## 1.6 Normalization

Before feeding the data to the models, we need to make the patches height invariant to correctly normalize different patches taken from different maps with different height scaling factor. To do so, we subtract the height of the map corresponding *Krock*'s position from the patch to correctly center it. The following figure shows the normalization process on the patch with the square in the middle.

## 1.7 Data Augmentation

Data augmentation is used to change the input of a model in order to produce more training examples. Since our inputs are heightmaps we cannot utilize the classic image manipulations such as shifts, flips, and zooms. Imagine that we have a patch with a wall in front of it, if we random rotate the image the wall may go in a position where the wall is not facing the robot anymore, making the image now traversable with a wrong target. We decided to apply dropout, coarse dropout, and

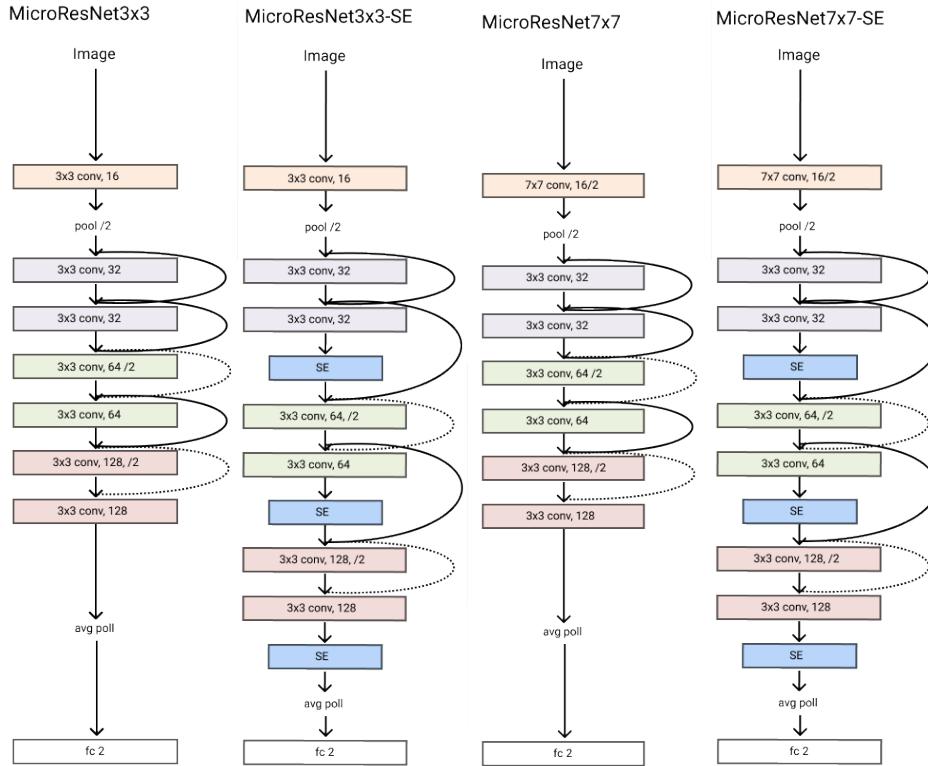


Figure 1.24. MicroResNet architectures for classification. All models have an initial features size of 16 and  $n = 1$  with and without the Squeeze and Excitation module. The rectangle represent the building block of each layer. Convolutiol layers are described by the kernel size, the number of filters and the stride. Lines and dashed lines between layers represent the residual operations and the shortcut respectively.

Input	(1, 78, 78)			
Layers	$3 \times 3, 16$ stride 1		$7 \times 7 16$ stride 2	
	2 $\times$ 2 max-pool			
	$3 \times 3, 16$		x 1	
	SE	-	SE	-
	$3 \times 3, 32$		x 1	
	$3 \times 3, 64$			
	SE	-	SE	-
	$3 \times 3, 64$		x 1	
	$3 \times 3, 128$			
	SE	-	SE	-
average pool, 1-d fc, softmax				
Parameters	313,642	302,610	314,28	303,250
Size (MB)	5.93	5.71	2.41	2.32

Table 1.2. MicroResNet architecture. First layer is on the top. Some architecture's blocks are equal across models, this is shows by sharing columns in the table.

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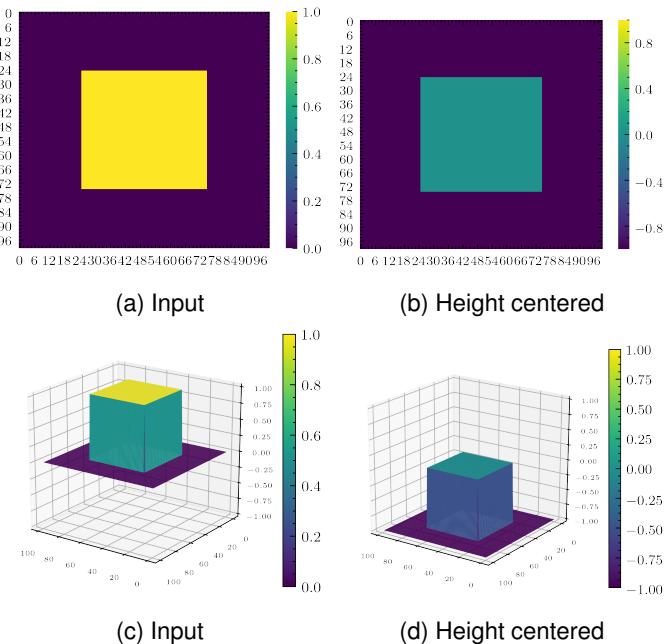


Figure 1.25. Normalization process. Each patch is normalized by subtracting the height value corresponding to the robot position to center its height.

random simplex noise since they are traversability invariant. To illustrate those techniques we are going to use the same square patch showed before 1.25.

### 1.7.1 Dropout

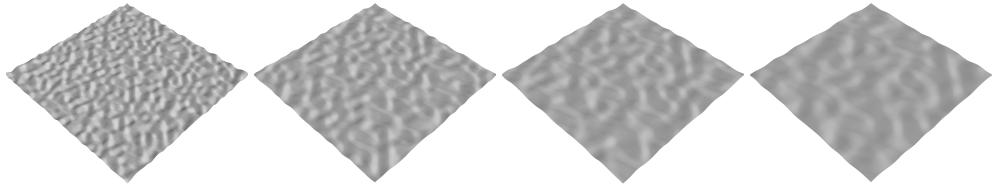
Dropout is a technique to randomly set some pixels to zero, in our case we flat some random pixel in the patch.

### 1.7.2 Coarse Dropout

Similar to dropout, it sets to zero random regions of pixels with defined boundaries.

### 1.7.3 Simplex Noise

Simplex Noise is a form of Perlin noise that is mostly used in ground generation. Our idea is to add some noise to make the network generalize better since lots of training maps have only obstacles in flat ground. Since it is computationally expensive, we randomly fist apply the noise to five hundred images with only zeros. Then, we randomly scaled them and add to the input image.



(a) Features size = 10 (b) Features size = 20 (c) Features size = 30 (d) Features size = 40

Figure 1.26. Simplex noise on flat ground. The feature size corespond to the amount of noise we introduce in the surface. A lower value produces noisy grounds, while a bigger one smoother terrains.

Figure ?? shows the tree data augmentation techniques used applied the input image. To ensure we do create untraversable patches from traversable patch we limited the coarse dropout region to only few centiments and we apply a smoother simplex noise on traversable patches. In detail, in all the traning epochs, we augmented 80% of the input images with dropout and coarse dropout. Dropout has a probability between 0.05 and 0.1 and coarse dropout has a probability of 0.02 and 0.1 with a size of the lower resolution image from which to sample the dropout between 0.6 and 0.8. Simplex noise was applied on the 70% of the training data samples with a feature size between 1 and 50 with a random scaling factor between 15–25 and 5–15 from traversable and not traversable patches respectively.

## 1.8 Tools

We quickly list the most important tools and libraries adopted in this project. The framework was entirely developed on Ubuntu 18.10 with Python 3.6.

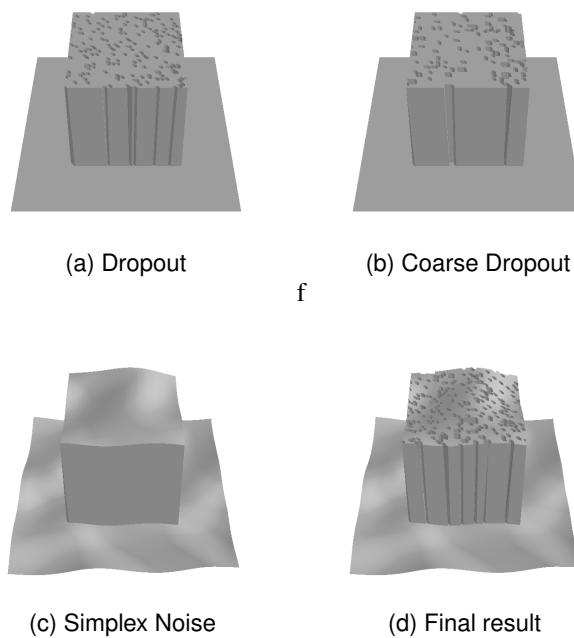


Figure 1.27. Data augmentation applied on a patch. First we randomly set to flat some small regions of the ground. Then, we slightly mutate the surface using simplex noise.

### 1.8.1 Software for simulation

**ROS Melodic** The Robot Operating System (ROS) ? is a flexible framework for writing robot software. It is *de facto* the industry and research standard framework for robotics due to its simple yet effective interface that facilitates the task of creating a robust and complex robot behavior regardless of the platforms. ROS works by establishing a peer-to-peer connection where each *node* is to communicate between the others by exposing sockets endpoints, called *topics*, to stream data or send *messages*. Each *node* can subscribe to a *topic* to receive or publish new messages. In our case, *Krock* exposes different topics on which we can subscribe in order to get real-time information about the state of the robot. Unfortunately, ROS does not natively support Python3, so we had to compile it by hand. Because it was a difficult and time-consuming operation, we decided to share the ready-to-go binaries as a docker image.

### 1.8.2 Data processing

**Numpy** Numpy is a fundamental package for any scientific use. It allows to express efficiently any matrix operation using its broadcasting functions. Numpy is used across the whole pipeline to manipulate matrices.

**Pandas** To process the data from the simulations we rely on Pandas, a Python library providing fast, flexible, and expressive data structures in a tabular form. Pandas is well suited for many different kinds of data such as handle tabular data with heterogeneously-typed columns, similar to SQL table or Excel spreadsheet, time series and matrices. We take advantages of the relationa data structure to perform custom manipulation on the rows by removing the outliers and computing the advancement.

Generally, pandas does not scale well and it is mostly used to handle small dataset while relegating big data to other frameworks such as Spark or Hadoop. We used Pandas to store the results from the simulator and inside a Thread Queue to parse each .csv file efficiently.

**OpenCV** Open Source Computer Vision Library, OpenCV, is an open source computer vision library with a rich collection of highly optimized algorithms. It includes classic and state-of-the-art computer vision and machine learning methods applied in a wide array of tasks, such as object detection and face recognition. We adopt this library to handle image data, mostly to pre and post-process the heatmaps and the patches.

### CNN training

**Pytorch** PyTorch is a Python open source deep learning framework. It allows Tensor computation (like NumPy) with strong GPU acceleration and Deep neural networks built on a tape-based auto grad system. Due to its Python-first philosophy, it is easy to use, expressive and predictable it is widely used among researchers and enthusiast. Moreover, its main advantages over other mainstream frameworks such as TensorFlow ? are a cleaner API structure, better debugging, code shareability and an enormous number of high-quality third-party packages.

**FastAI** FastAI is library based on PyTorch that simplifies fast and accurate neural nets training using modern best practices. It provides a high-level API to train, evaluate and test deep learning models on any type of dataset. We used it to train, test, and evaluate our models.

**imgaug** Image augmentation (imgaug) is a python library to perform image augmenting operations on images. It provides a variety of methodologies, such as affine transformations, perspective transformations, contrast changes and Gaussian noise, to build sophisticated pipelines. It supports images, heatmaps, segmentation maps, masks, key points/landmarks, bounding boxes, polygons, and line strings. We used it to augment the heightmap, details are in section 1.7

### 1.8.3 Visualization

**matplotlib** Almost all the plots in this report were created by Matplotlib, is a Python 2D plotting library. It provides a similar functional interface to MATLAB and a deep ability to customize every region of the figure. All It is worth citing *seaborn* a data visualization library that we inglobate in our work-flow to create the heatmaps. It is based on Matplotlib and it provides an high-level interface.

**mayavi** Mayavi is a scientific data visualization and plotting in python library. We adopt it to rendered in 3D all the surfaces used in our framework.