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Sequential Action Selection for Budgeted Localization in Robots

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Abstract—Recent years have seen a fast growth in the number of applications of Machine Learning algorithms from Computer Science to Robotics. Nevertheless, while most such attempts were successful in maximizing robot performance after a long learning phase, to our knowledge none of them explicitly takes into account the budget in the algorithm evaluation: e.g. budget limitation on the learning duration or on the maximum number of possible actions by the robot. In this paper we introduce an algorithm for robot spatial localization based on image classification using a sequential budgeted learning framework. This aims to allow the learning of policies under an explicit budget. In this case our model uses a constraint on the number of actions that can be used by the robot. We apply this algorithm to a localization problem on a simulated environment. Our approach enables to reduce the problem to a classification task under budget constraint. The model has been compared, on the one hand, to simple neural networks for the classification part and, on the other hand, to different techniques of policy selection. The results show that the model can effectively learn an efficient policy (i.e. alternating between sensor measurement and movement to get additional information in different positions) in order to optimize its localization performance under each tested fixed budget.

I. INTRODUCTION

Spatial localization is one of the most challenging problems in Robotics. The main problem consists in taking a spatial decision in the environment in order to localize itself on a map using the different sensors that are available to the robot. The processing of these data is generally difficult because of their multimodality. The problem is made even more difficult by the mutual dependency of the localization and mapping steps: in order to localize itself, the robot needs to recognize cues and features which characterize a particular place and which have previously been perceived and stored. Conversely, to build a reliable map and correctly situate features within it, the robot needs to be able to localize itself relative to these features [1].

While several mapless robot navigation solutions exist [2], the problem of robotic localization has been classically and widely studied using the Self Localization and Mapping framework (SLAM, [3]; [4]; [5]), which proposes to simultaneously realize the localization and mapping steps. While SLAM methods may have difficulties during long navigation experiments – facing the loop closure problem where the robot needs to reset its estimations when recognizing a previously visited place, or having difficulties satisfying the hypothesis of a static world

on which SLAM is anchored (see [6] for discussion) –, SLAM methods can produce robust and efficient localization when no limit is set on the amount of data and sensors which can be processed by the robot. However, while SLAM works both with lasers and cameras. Moreover, SLAM is not concerned with action selection, and thus cannot tell how information gathering for the localization process should be integrated within the global policy of the robot to maximize a given reward function.

Machine Learning research has recently come up with formal solutions to take into account an explicit budget for image recognition or data classification [7], [8], [9]. In particular, specific algorithms called Sequential Budgeted Learning algorithms are used in order to learn sequences and representations from limited amounts of data, which offers the possibility of adding an explicit budget to limit the model. One of the goals of these approaches is to limit the number of costly accesses to data to the minimum required for successful classification. One way to do that is to incorporate the decision to access or not to access data in the policy of the agent, so that it learns to timely access data among other possible actions.

The idea of data acquisition considered as an action is also at the core of the active sensing field, mainly developed in the 2000's. However, these techniques are limited by the fact that the systems learn action sequences having already learned the task representation. As shown in [10], the main technique used in the active sensing field is based on maximizing a weighted sum of rewards associated to a sequence of actions executed by a robot.

In this paper, we propose a model that makes a robot use as minimum data as possible to learn representations from the environment and to learn an optimal policy in order to accomplish a localization task. Hence, our problem is defined within a mapless navigation framework: the robot uses only the perceptions obtained via its sensors to take a spatial decision and is not based on an explicit map.

II. RELATED WORK

The mapless navigation problem has been widely investigated since the late 90s. Different techniques are used and can be divided into three main subsets: optical flow, appearance or object recognition based navigation [11]. The first category resumes the techniques that are based on the motion of all the

surface elements from the visual world. The robot localizes itself using the velocity of the different images [12], [13], [14], [15], [16]. The second category describes the techniques that rely on memorizing the working environment: the idea is that in a way or another the robot stores images of the environment and then compares the received images in an online phase with the stored memory. The last category is based on objects and landmarks recognition in the environment.

Our approach belongs to the second category: appearance-based navigation, usually consisting in two different phases. First, a training phase where the robot learns the places in the environment from the recorded images. Second, a navigation phase where the robot has to recognize the places by comparing them to the images stored during the training phase. In this context, [17] performs indoor route construction by comparing the current image with the training data set, simply calculating a distance between them. In [18] the robot creates a sequence of images by storing the motion associated to each image. [19] use a histogram representation for the images encountered in a training phase and during the inference they compare the new images to the training samples with a quadratic distance to localize the robot in its environment. Our case is slightly different from these papers since, in the training phase, we do not extract specific informations from the images (only the RGB description). The work described here can also be compared to the active sensing literature [10], whose main goal is to minimize the acquired data in order to complete a task.

On the other hand the machine learning field has developed different ways of analyzing data. The recent deep learning state-of-the-art has many promising results on how data are processed in order to make agents learn representations, policies or both. More specifically, algorithms in the budgeted learning field have been studied in order to make agents learn from limited amounts of data. In [7] the authors have a sequential architecture, where the model learns representations at each time step using sequentially given data, but the available amount of data is unlimited. A budgeted version of this model was recently proposed in [20]. In both papers, it is specified that data are given between each transformation step. A similar architecture has been presented in [9], where the authors used an explicit budget but with no observations (or data) between each step.

Our model proposes a version where we use both approaches described above. The model uses an explicit budget and observations are returned given the action that the agent performs.

III. MODEL

A. Principles

We propose a model applied to a localization task, where the model aims at learning which action to choose in a set of possible actions (movement or acquisition of new information) at each time step. The model is restricted by a budget B that limits the number of actions allowed in order to complete the task in a given environment. We aim at learning to

alternate between movements and data acquisition in order to collect relevant information and thus to localize efficiently. Our algorithm relies on the Deep Reinforcement Learning paradigm i.e learning a neural network-based policy by using reinforcement learning techniques, more precisely by using policy gradient techniques [21], where the model will reinforce the sequence of actions that allowed it to successfully complete the task. However in our case, the policy learning is not driven by a reward signal but by a defined loss function Δ that computes the quality of the system resulting in a model different than classical RL approaches.

Model Description

Let us denote \mathcal{X} the set of all the possible positions of the robot in a particular given environment. At the beginning of each episode, when $t = 1$, the robot will be at a particular unknown position denoted x . Then, by sequentially choosing actions a_t at each time step t in the set of all possible actions \mathcal{A} , the robot will either gather a new information by using one of its sensor, or move in the environment. At the end of the process, the robot will predict its position y . The quality of the prediction will be measured through a differentiable loss function $\Delta(x, y) \in \mathbb{R}^+$.

Let us denote o_t the observation acquired by choosing action a_t such that $o_t \in \mathbb{R}^{n_{a_t}}$, n_{a_t} being the size of the observation space corresponding to action a_t i.e the size of the acquired information if a_t is a sensor acquisition action, or 0 if a_t corresponds to a robot movement. Note that this assumption is different then the classical assumption of Reinforcement Learning where an agent receives at each time step an observation from the same observation space. The value of o_t is defined by the unknown probability $P(o_t|a_t, a_{t-1}, \dots, a_1, x)$ which depends on the environment. We will denote $\pi(a_t|a_{t-1}, o_{t-1}, \dots, a_1, o_1)$ the policy of the robot, i.e the probability of choosing action a_t knowing the previously acquired information o_{t-1}, \dots, o_1 and the previously chosen actions a_{t-1}, \dots, a_1 . The final decision function which will predict the robot position w.r.t acquired information will be denoted $f(a_t, o_t, a_{t-1}, o_{t-1}, \dots, a_1, o_1, x)$.

Learning Algorithm

Let us denote (x_1, \dots, x_m) the set of training positions i.e the m robot positions that will be used during training. Let us denote B the maximum number of actions allowed to the robot¹. The learning objective is to find both the policy π^* and the prediction function f^* that minimize the prediction error:

$$\pi^*, f^* = \arg \min_{\pi, f} L(\pi, f) \quad (1)$$

where

$$L(\pi, f) = \mathbb{E}_{\pi}[\Delta(f(a_B, o_B, \dots, a_1, o_1, x), y)] \quad (2)$$

where the trajectories $a_B, o_B, \dots, a_1, o_1$ are sampled following π . The minimization of this objective will be made by using policy gradient techniques proposed in [9].

¹We consider that B is fixed, the extension of this model to variable number of steps being the object of a future research.

Type	Budget		
	1	3	5
Image classification	53.9	56.6	59.8
Forced policy			
Recurrent	49.9	67.4	75.9
Non Recurrent	55.8	60.8	61.2
Learned policy			
Recurrent	52.9	61	70
Non Recurrent	46.8	69.4	60.04

TABLE I

RESULTS FOR SIMULATED CASE. RESULTS REPRESENT PERFORMANCE ON TEST SET (IN PERCENTAGE)

First, one can see that the quality of the classification model improves when the number of acquired images increases. It confirms that providing more information to the agent helps him to compute a better localization than a single image. Moreover, when using the *Forced policy*, the model is able to achieve 75.9% when collecting 3 images ($B = 5$) and thus to increase its performance by 50% w.r.t using only 1 image. The *Learned policy* model is able to achieve a 70% accuracy on the same task showing that the agent has learned a relevant policy and has been able to discover how to move and when to acquire information. Note that the *recurrent* versions of the two models give a better performance since they need to estimate a smaller number of parameters than the *non recurrent* versions allowing a better generalization

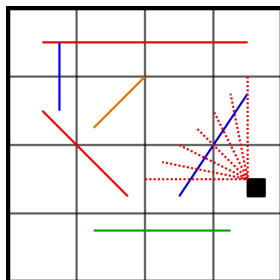


Fig. 1. Simulated data. The black square represents the robot. The dotted lines represent the range of the camera. The plain colored lines represent randomly placed walls. The horizontal and vertical lines represents the spatial discretization.

V. CONCLUSION

We have introduced in this paper a new learning model where an agent can decide when to acquire information for a given localization task. It corresponds to an original problem where the information acquisition has a cost which is different to the classical paradigm where information is gathered at each time step. We have proposed a set of preliminary experiments showing the interest of this approach. Future research directions include the evaluation of this model on a real robotic task where the robot has multiple sensors, each sensor being associated to a particular cost. Moreover, we plan to investigate an extension of this model where the number of steps is

not fixed, and where the agent can decide when to stop the sequential acquisition process.

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