Statement of Objectives

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I obtained my master's degree in Robotics at ETH Zurich, where I broadly researched learning-based robot control and exploration planning. My master thesis aimed to leverage optimality from the model-based approach to the network-based controller and achieve smooth sim-to-real transfer. I also actively researched exploration planning and proposed a framework to learn the sampling distribution from next-best-view samples and bias the exploration towards the frequently visited area. Both works are turning into publications and have addressed different aspects of robot autonomy: motor and sensing. These, together with my short stay as a SLAM engineer for a driverless car organization, motivate me to create a tight integration between perception and control. Towards that end, I joined Prof. Amir Zamir's group at EPFL as a graduate research intern and I am currently investigating the general framework of goal-conditioned navigation and exploration using the knowledge about the visual experiences. I believe that with a better understanding of how visual modality is used to update the robot internal memory as well as to assist the downstream tasks, I will be a step closer to my future goal of developing an inseparable, yet interpretable training paradigm for robotics, and finally closing the perception-control loop.

Graduate Research

Research in Learning-based Control During my studies at ETH Zurich, my research mainly focused on the learning-based autonomy of mobile robots, including perceptive control, planning, and trajectory optimization. In my thesis (Ni, 2021), I used imitation learning to leverage knowledge from the Model Predictive Control (MPC) expert to the network-based controller under structured terrain. This enables the robot to be aware of the obstacles and move accordingly. Unlike traditional behavior cloning, we optimize for the policy using control Hamiltonian as the objective and achieve better learning performance. We also adopted a two-stage teacher-student learning framework to handle the noisy elevation map. Our work trained the network in simulation with demonstrations collected from a reliable MPC expert and achieved sim-to-real transfer. Additionally, the trained policy behaves like a model-based expert but can be inferred at a low computational cost.

Research in Exploration Planning I am also interested in the planning of the robot where the robot has to either explore the environment or find an object with limited battery power. In another work (Schmid et al., 2021) with Prof. Roland Siegwart, I developed the framework for sampling exploration waypoints from a learned distribution in an unknown environment. We used conditional variational auto-encoder (CVAE) to learn the latent representation of best samples collected from a uniform planner and to generate sampling points. Our framework can achieve faster exploration and provides a general exploration strategy as an alternative to random sampling methods for multiple downstream tasks, such as goal-reaching or object-seeking navigation problems.

Current Research

Research in Graph Distillation My previous works focus on the problem of *how* and *where* to move in the local environment, however, a fully autonomous robot requires a long-range sight and long-term memory, where the robot will be experienced with realistic perception input and has an internal memory scheme. With the idea of bridging memory-rich and realistic visual input to the movement of the robot, I joined Amir Zamir's group at EPFL. I am currently working on the goal-conditioned navigation problem, where we actively distill the memory graph to reserve a compact structure. For a navigation problem, the internal memory can be carried along with a general-purpose memory module such as LSTM within the vision-action module(s), but having a separate memory proves to be better. One way to represent the memory is to build a graph. The issue facing the graph construction is that when the exploration continues, more information comes into the graph, and simply adding new observations into the graph will cause memory difficulty, as well as degradation of the visual localization and graph resorting performance. By distilling the graph, the issue can be solved.

Future Research Goal

Professional Goal My professional goal is to become a researcher and entrepreneur in the area of robotics, and my research endeavor during my Ph.D. will be to close the perception-control loop for the robot. I hope to build systems where the robot is able to learn from its own interactions with the environment. With these systems, life-long learning can be achieved and massive applications of robots will come into being.

Tight Perception-action Integration In the near future, my interest lies in creating tight integration between perception and control. Current approaches tend to decouple these two and treat them in isolation. However, this is not always the case for a more intelligent robot. A cheetah will adjust its moving direction and its gait based on the same perception towards its prey, this (long-term) perception input explains not only its seeking strategy (*planning*) but also how it drives its muscles (*control*). Specifically, I want to create an end-to-end trainable framework for robotics applications, where each module is connected conceptually and can be trained in parallel or in an alternating fashion. The aim is to have an inseparable, yet interpretable training paradigm and pave the way for closing the action-perception loop.

Communication with Memory Graph A parallel passion inspired by my current project lies in the treatment of the memory (graph) module for an autonomous agent. Alongside the forward inference in the perception-control framework, there is room for constructing the memory graph of the robot and investigating the communication between the (long-term) graph and the (immediate) vision-action inference. Valuable research directions regarding graphs include a) its independence relative to the perception-control module(s); b) its bidirectional communication with the vision-action inference; c) its sub-graph structure implies the task-dependent behavior of the robot.

Reference:

Ni, C. (2021), *Learning to Walk Over Structured Terrains by Imitating MPC* [Master thesis, ETH Zurich]. https://chaofiber.github.io/data/master_thesis.pdf
Schmid, L., Ni, C., Zhong Y., Srinivasan, S., Cadena, C., Siegwart, R., and Andersson, O. (2021). *Learning Sampling-based Exploration Planning*. Unpublished manuscript, ETH Zurich, Zurich, Switzerland.