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Angle and position perception for exploration with active touch

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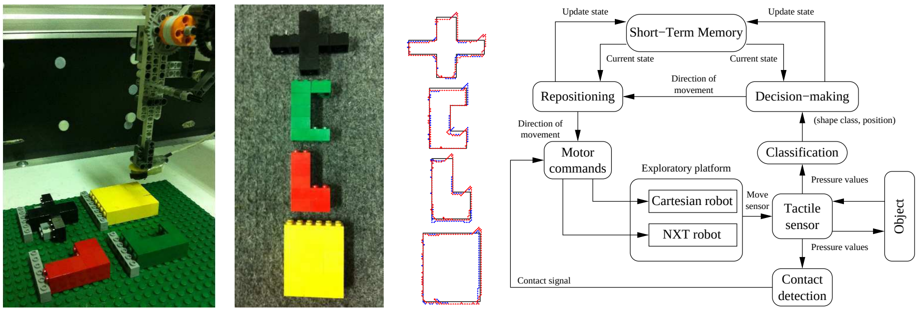
Over the past few decades the design of robots has gradually improved, allowing them to perform complex tasks in interaction with the world. To behave appropriately, robots need to make perceptual decisions about their environment using their various sensory modalities. Even though robots are being equipped with progressively more accurate and advanced sensors, dealing with uncertainties from the world and their sensory processes remains an unavoidable necessity for autonomous robotics. The challenge is to develop robust methods that allow robots to perceive their environment while managing uncertainty and optimizing their decision making. These methods can be inspired by the way humans and animals actively direct their senses towards locations for reducing uncertainties from perception [1]. For instance, humans not only use their hands and fingers for exploration and feature extraction but also their movements are guided according to what it is being perceived [2]. This behaviour is also present in the animal kingdom, such as rats that actively explore the environment by appropriately moving their whiskers [3].

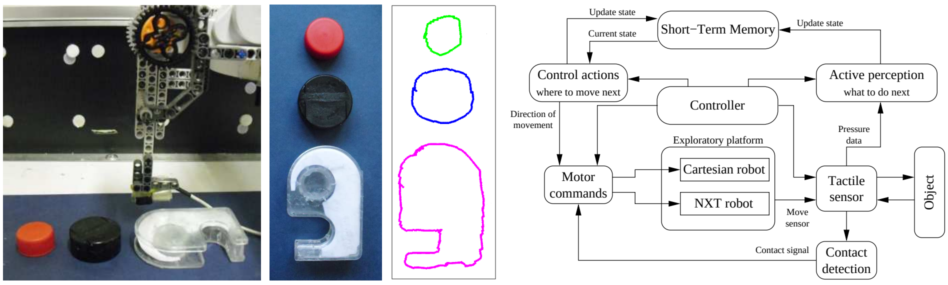
We are interested in the development of methods for perceiving the world through the sense of touch. Even though other sensory modalities such as vision have been widely studied, we are principally motivated by the way humans and animals rely on their sense of touch, such as in situations where vision is partial or occluded, as in a smoke-filled buildings or darkness. In this study we show how active Bayesian perception is important for decision making with a robotic fingertip. First, we present an approach based on maximum likelihood using one tactile contact for decision making. Then, we show an improvement using an active Bayesian perception approach where the tactile sensor performs contacts until the system has sufficient confidence to make a decision. To test the different approaches, we choose the simple but illustrative task of contour following. The aim of the task is to perceive the angle and position where the robotic fingertip is in contact with the edge of the object. For this task, the robot needs to make decisions about *what to do next* and *where to move next*, which results in an active exploration strategy that extracts the shape of the object.

First, we developed and implemented a tactile perception method based on maximum likelihood where only one tactile contact is required for making a decision [4,5,6]. We used data collected from an edge of 4 different angles separated by 90 degs. For each angle we gathered 18 position classes, to give a total 72 perceptual classes for discrimination. Two data sets were collected to have one for



(a) (b) (c) (d)

Fig. 1: Active perception based on maximum likelihood. (A) Test robot. (B) Test objects. (C) Results showing the traced contours. (D) Sensorimotor architecture for robot control.



(a) (b) (c) (d)

Fig. 2: Active Bayesian perception approach. Labels as in Fig. 1.

training and one for testing. The training was performed off-line and the testing performed in real-time on-line using a sensorimotor architecture controlled by the tactile perception. The objects used for this experiment and the results are shown in Figure 1. The robotic fingertip was able to successfully trace the contour of the objects using this approach (Figure 1c). This was accomplished by actively moving the fingertip perpendicularly to the current edge while following the contour of the object. This active repositioning is responsible for ensuring that the tactile sensor will be placed in an optimal location for improving perception.

We developed a second method to improve the perception of complex object shapes, covering a wide range of angle classes. To achieve this improvement, we developed an active Bayesian perception method inspired by previous studies where different stimuli were successfully classified [7,8,9]. In active Bayesian perception, the robot accumulates perceptual evidence through successive contacts with an object. Once the evidence accumulated is sufficient for the perceptual beliefs to cross a threshold, a decision about the angle and position classes is triggered. This method is inspired by the way animals make decisions based on the experience accumulated through the interaction with the environment [5]. Here, we collected 72 angle classes in 5 deg steps from a circle covering 360 degs. For each angle, we gathered 18 position classes, giving a total of 1296 distinct perceptual classes for discrimination. The training was performed off-line, with results that showed the best location for perception is in the centre (9 mm position class) of the fingertip sensor, which corresponds with previous work [6,7,9]. Also, in the off-line analysis we estimate the mean angle and position errors against belief threshold and reaction time (number of taps) to make a decision. For passive perception we obtained mean angle and position errors of about 12.2 degs and 0.8 mm, whilst for active perception we obtained substantially improved results of 3.3 degs and 0.2 mm. The reaction time for making a decision was 4-6 taps.

To demonstrate the accuracy of the method with the robot, we implemented a sensorimotor architecture to trace the contour of different objects (Figure 2d). This architecture implements *what to do next* and *where to move next* decisions based on the tactile perception interacting with the object properties. We used two circles with 2 cm and 4 cm diameters and one asymmetric object (Figure 2b). The contours around the objects were successfully traced (Figure 2c) using a belief threshold of 0.8 for making a decision at each position of the contour. An average of 6 taps were needed for the robot to make a decision. From these results, we observe that the traced contours accurately represent the different object shapes. This shows that the robot is able to behave correctly according to the task specified.

The methods presented in this study showed that active perception provides an effective way of dealing with uncertainty. Also, we observed how active perception can be used for controlling a system according to the perceptual information received. We expect that this approach will lead to robust and accurate methods for autonomous robots to interact with, explore and perceive their environment.

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