Concept Acquisition Using Isomap On Sensorimotor Experiences Of A Mobile Robot

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Abstract

We present recent results about the application of a novel method for multi dimensional scaling (Isomap) for concept acquisition in mobile robotics. The aim of this work is to develop a general architecture for Symbol Anchoring in the context of research to enable artefacts to grow-up. We describe Isomap functionality, results of using it in a real robot and briefly discuss implications of using this technique for concept acquisition in the mobile robot domain.

1. Introduction

Recently, concept acquisition in mobile robots attracted the interest of researchers in robotics (Coradeschi and Saffiotti, 2003), but also in cognitive science and related fields. The problem how an autonomous mobile robot can acquire conceptual knowledge about its environment arises from interest in human concept acquisition, but also from a more technical perspective of mapping objects in the robot's environment on structures internal to the robot ("Symbol Anchoring"). Thirdly, concept acquisition can be regarded as a step in addressing Stevan Harnad's "Symbol Grounding Problem" (Harnad, 1990).

Our approach described here investigates the applicability of novel statistical tools and robust techniques for the discovery and formation of conceptual knowledge in an autonomous robot. Our work aims at developing a general symbol anchoring architecture in the context of research that aims at intelligence for artefacts that grow-up. We test the architecture in a number of scenarios, one being the "search and find things" scenario in which the robot first acquires names for objects to wander off and find them.

The robot used for the experiments is a research test platform with six wheels, twelve infrared sensors, two sonar sensors and a laptop used for control. The robot has originally been designed for sewage pipe inspection experiments and is controlled by software developed at our institute. The test environment consists of rooms in our offices equipped with a number of cardboard boxes, bins etc. as obstacles.

2. The Approach

Describing environmental features in terms of what the robot perceives and does is difficult for a number of reasons. Apart from noisy sensor readings and problems related to the reliability of typical mobile robot sensors, finding structure in robot sensor data is demanding due to the high-dimensionality of this data. However, often the complete high-dimensional space is only sparsely populated by sensor data and could be embedded in lower dimensions. Our approach is based on finding an embedding of the high-dimensional sensor space including motor information into low dimensionality. We use Isomap, a novel statistical procedure for nonlinear dimensionality reduction (Tenenbaum et al., 2000) capable of performing multi dimensional scaling. In a second step, low-dimensional isomapped sensory-motor data of the robot is used for the construction of prototypes that correspond to object-like features of the environment.

Isomap is capable of preserving the nonlinear structure of the input data as captured in the geodesic manifold distances between all pairs of data points. The problem of calculating the distances of distant points is solved using the input space distances for neighbouring points (which provides a good approximation) and then, for distant points, approximating the geodesic distance by summing sequences of "short hops" between neighbouring data points. This creates a distance matrix for all data points to which classical MDS (Kruskal, 1964) is applied.

We calculate the error in an Isomap of robot data for a sequence of lower-dimensional embeddings and use the elbow of this error curve for the decision on which dimension to use. This dimensionality of our data seems to be three.

3. Results

Concept acquistion in our robot architecture comprises serveral steps. First, the isomap is trained in the robot's typical surroundings until a certain stability is reached. This means that we collect motor (left and right speed) and sensor (twelve infrared and two sonar sensors mounted round the robot) data of the exploring robot and adapt the isomap accordingly. This generates a three dimensional embedding of the data.

Then the map is "frozen" and new data is mapped by projection onto existing isomap points choosing the nearest one. This produces a "smart sensor stream", which in the next step is used to extract sequences of points. We call these sequences events and identify them based on large "jumps" within the map. Similar perceptions are mapped onto similar patterns in the isomap, thus a simple eucilidian distance measure can be used for categorisation (cf. Figure 2).

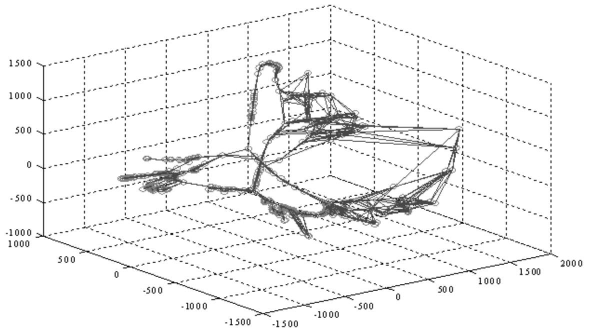

Figure 1: Three dimensional Isomap of a one minute sequence of 16 dimensional robot sensory and actory data.

A great advantage using Isomap in our domain is that analogical "reasoning" can be carried out by linear operations in the feature space created. This means that the robot can make forecasts of what will happen next just by examination of the space in the vicinity of its current Isomap position (with probability decreasing proportionally to the distance).

Figure 2 shows an Isomap of two typical and similar robot situations as it passes a tube on its left side while navigating along a corner in a room. The graphical (and euclidian) distance in the two plotted trajectories results from the fact that the robot passed the tube closer in run two. Note that the two situations are classified as the same category.

One crucial question concerns the need to partition the sensory streams in terms of the physical entity of the robot. It turned out to be worthwhile not to use all sensory input at once but to split the data stream in two halves corresponding to the left and right side of the robot. This serves to keep lateral discrimination information. As an example, consider the robot as it passes a tube to its left side and a box on its right: Using the whole sensor stream for the Isomap this would be scaled down to just one situation and hide the information that both events are distinct. Using "hemispheres" (right and left sensors) for the Isomap procedure is beneficial in terms of data compression, information preservation, and also performance.

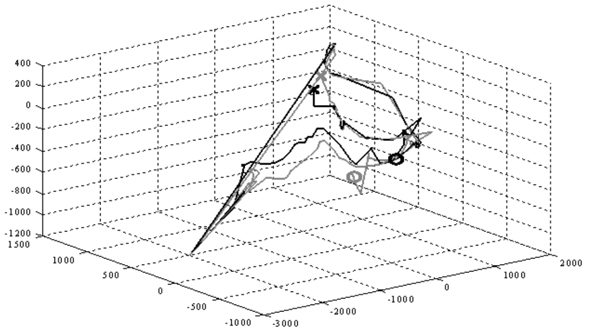

Figure 2: Three dimensional Isomap of two similar robot situations (grey and black). X marks the starting and O the endpoints of the trajectories.

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