A Correspondence Metric for Imitation

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Introduction

Learning by imitation is a powerful form of learning. Different forms of imitation, like mimicry, copying, response facilitation, etc. have been studied extensively (Miklosi 1999). Recent research in robotics has begun to explore imitation as a means to allow complex robots, like humanoid robots, acquire new skills (Swinson & Bruemmer 2000).

One of the key issues in imitation learning is the *correspondence problem*. This problem concerns the answer to the question: *what action sequence of the imitator is similar to that of the demonstrator and how similar it is?* The notion of "similarity" has remained subjective thus far. Robotics research in imitation has mostly focussed on action learning and classification, and not on the correspondence problem. Our aim is to develop a generalized metric that provides a scalar measure of dissimilarity/distance between any given pair of action sequences. This, we expect would be a uniform means to evaluate imitation in agents. The metric can also be used as a part of the action selection mechanism in an imitator agent.

Related work

Nehaniv et al. (Nehaniv & Dautenhahn 2000; 2001) have provided a formal framework for the correspondence problem. Within this framework, Alissandrakis et al. (Alissandrakis, Nehaniv, & Dautenhahn 2002) have explored multiple metrics. These have however been specific to the particular agents and problems considered.

Pomplun et al. (Pomplun & Matarić 2000) have used four different metrics to evaluate imitation of arm movements. These metrics used scaled and time-normalized Euclidean distance. These are specific to the experiment, and cannot be used as a general metric for correspondence.

Research in object recognition has resulted in the development of metrics that compare object silhouettes (Liu & Geiger 1999; Sebastian, Klein, & Kimia 2001). These methods are not directly extendable to motions or actions of articulated agents.

The Approach

We consider agents as simple open kinematic chains. We represent each chain as a *tree*, termed *kinematic tree* or *k-tree*. We introduce the following definitions.

Definition 1 (k-tree) *A* kinematic tree *or* k-tree *is an encoding of an open kinematic chain such that every link in the kinematic chain is represented by a unique edge in the k-tree.*

Definition 2 (Pose) *A* pose p *of a k-tree* t *is an assignment of the ordered pair* $\langle n_i, l_i \rangle$ *to every edge* e_i *of* t. n_i *is a unit normal that is the orientation of the link, represented by* e_i, *in the world coordinate frame.* l_i *is the length of the link represented by* e_i.

Definition 3 (Homeomorphic pose class) *A* homeomorphic pose class P *is a set of poses such that for any pair of poses* $p, q \in P$, *if* t_p *is the k-tree of* p *and* t_q *the k-tree of* q *then* t_p *and* t_q *are* homeomorphic.

We have developed an algorithm that computes a distance measure between a pair of poses that belong to a homeomorphic pose class. The algorithm first partitions the edges of each k-tree into disjoint sets. Based on the presence of a common minimal homeomorph for the two trees, the algorithm pairs the edge sets of the two k-trees. A distance measure, based on the summed squared difference of the instantaneous slopes is then used to compute the dissimilarity between individual pairs. The distance between the two poses is the sum of all the dissimilarity measures. The distance thus computed imposes a *pseudometric* over the homeomorphic pose class. Our algorithm thus provides a measure of dissimilarity between poses which can be used toward estimating pose correspondence.

Experimental Validation

In order to experimentally test the metric, we require agents with differing kinematic structures such that their poses belong to the same pose class. We chose to use three different agents for the purpose, a Sony AIBO (Figure 1) robot dog, a human, and a simulated dolphin-like structure (Figure 2).

Pose information for the AIBO was obtained by converting the joint angle values obtained from the software onboard to orientations in a world coordinate frame. For the human, digital images of the subject in various postures

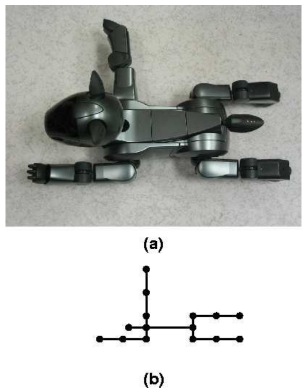

Figure 1: (a) Sony AIBO and (b) its k-tree representation

were captured and limb orientations were extracted and then encoded into *poses* (Figure 3).

For the experiments, we used 16 poses for each of the three agents for a total of 48 poses. All-pairs distances of the poses were computed based on the pseudometric. Figure 4 shows some closest pose pairs between agents.

We are currently extending the correspondence algorithm to allow comparisons between time-extended actions. Actions result in continuous curves in pose space, and hence comparisons can be made between curves.

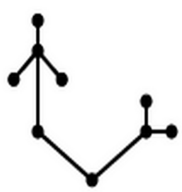

Figure 2: k-tree of the dolphin-like skeleton

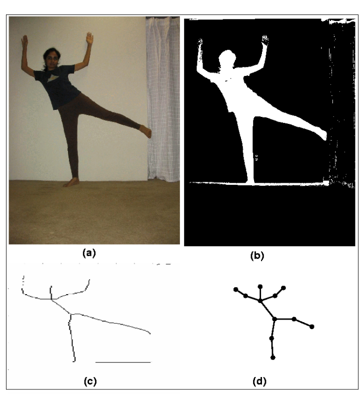

Figure 3: (a) Captured image (b) Image after background subtraction (c) Image after skeletonization (d) Computed pose

Figure 4: Top row: Closest AIBO pose to the dolphin pose; middle row: Closest AIBO pose to the human pose; bottom row: Closest dolphin pose to the human pose

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