Learning by Observation without Three-Dimensional Reconstruction

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Abstract. This paper presents a basic skill of imitation learning from observation towards developmental cognitive robotics which aims at providing a new way to understand the cognitive process of human beings by realizing artificial systems based on the internal observer's viewpoint. Unlike the conventional ones, the proposed method does not assume the global coordinate system in order to transform the observed motion in the demonstrator's coordinate system to the learner's one. Instead, the optic-geometrical constraint called "epipolar constraint" is used to reconstruct the view of the other agent, on which adaptive visual servoing is applied to imitate the observed motion. The experimental results and future issues are given.

1   Introduction

Learning capability is the most essential issue for designing cognitive robots who can emerge the intelligent behaviors through the interaction with their environments. Except for the simple toy problems, machine learning theories seems difficult to apply real robot tasks as they are due to the huge search space caused by multi-modal sensor space and many DOFs which also add much more uncertainties than computer simulation. Therefore, some kinds of *teaching* have been implicitly or explicitly involved to accelerate the real robot learning.

Teaching can be regarded as one of the design issues for the robot environment (the external learning structure) with which the learner can interact [1]. The external learning structure can be roughly represented in the space composed by three axes: (1) spatial axis: environmental setups such as configuration of obstacles or motion control of other agents, (2) temporal axis: learning scheduling such as LEM [2] similar to shaping in animal behaviors, and (3) interaction with instructor such as teaching by showing (learning from observation). We have used (1) and (2) in our learning schemes [3, 4, 5].

In this paper, we focus on the third one, teaching by showing, as one of the environmental design issue for the cognitive robotics. The central idea is that the learner should interact with the instructor with a capability of development from a viewpoint of the internal observer. The learner has less a priori knowledge from an external observer's view point such as knowledge of the global positioning or the kinematic structure of its own body. Therefore, the learner needs to understand the observed motion through its own sensory space.

Schaal [6] surveyed imitation learning methods from three different view points: behavioral and cognitive science, neuroscience and cognitive neuroscience, and robotics, AI, and neural computation. He emphasized the importance of imitation as the route to humanoid robot focusing the efficient motor learning, the connection between action and perception, and modular motor control in form of movement primitives, and pointed out the open problem such as learning perceptual representations, movement primitives, movement recognition through movement generation, and understanding task goals. The third topic is related to the recent finding that some of neurons called "mirror neuron" were active both when the monkey grasps or manipulates objects and when it observes the experimenter making similar actions. Rizzolatti and Arbib [7] speculated that the ability of imitate actions and to understand them could have subserved the development of communication skills based on the fact that similar system includes Broca area (known to be related to speech generation) in human brain.
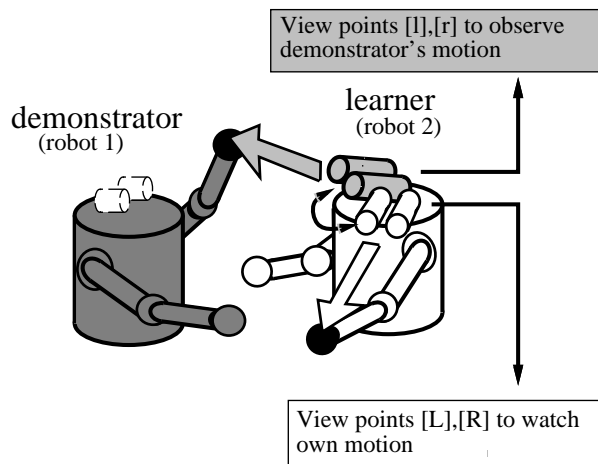

Figure 1: An imitation system

From a viewpoint of cognitive robotics, such a system should be included because capabilities of both motion generation by imitation and motion understanding (matching with own motion repertory) seem necessary. When it attempts at imitating the observed motions, the robot has to have a transformation system of the observed motion from the demonstrator's coordinate to its own one. Also, when it try to understand the observed motion, it seems necessary to have the similar system. If the exact transformation matrix is explicitly given, the problem seems simple and straightforward. From a viewpoint of the internal observer, such a transformation matrix is not available, but it has to find a mechanism to finally realize such a transformation. In the rest of this paper, we show a basic skill of imitation with less explicit knowledge of coordinate transformation, and discuss the future issues.

2   Imitating observed motion without 3-D reconstruction

The existing methods (ex. [8, 9]) for imitation usually include the three-dimensional reconstruction process of the observed data in order to transform them into its own coordinate system. Generally, three-dimensional reconstruction from two-dimensional images is an ill-posed problem, which leads time-consuming computation and error-prone results.
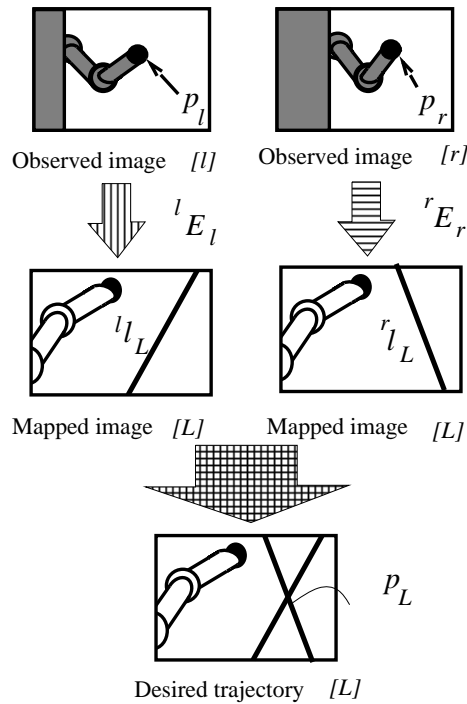
Figure 2: Mapping the epipolar lines

Here, we propose a simple imitation system of the observed action [10]. Instead of the three-dimensional reconstruction, we assume that the demonstrator (teacher) and the learner have the same body structure and the learner knows the correspondence between its body parts and the teacher's ones. Based on the stereo epipolar constraint [11] by which the projection of the object point in three-dimensional space is constrained onto the line of one image plane, and the adaptive visual servoing (hereafter, AVS) [12] consisting of an on-line image Jacobian estimator and a feedback/feedforward controller for uncalibrated camera-manipulator systems, the learner can generate the observed motion.

3   The method

Fig.1 illustrates a setup of the imitation system in which the demonstrator (robot1) shows its motion before the learner (robot2) that observes it. Since the AVS needs the desired trajectory in the sensor space to imitate, the problem is how to generate this trajectory on its own image plane from the observed motion. The basic idea is that the demonstrator's motion projected on the learner's image plane can be mapped onto the same plane (learner's) by assuming that the current view is observed from the demonstrator. To realize it, the epipolar constraint is applied twice to decide one unique image points as an intersection between two epipolar lines from the pair of the stereo images (see Fig.2).

Here, we briefly explain the stereo epipolar constraint. Observing a 3-D space point $\boldsymbol{P}$ by a pair of stereo cameras $[l]$ and $[r]$, its projection $\boldsymbol{p}_l$ onto the image plane $[l]$ constrains the other projected point $\boldsymbol{p}_r$ onto the line called epipolar line $\boldsymbol{l}_r$ in the image plane $[r]$. This relationship can be described by the following equation.

$$\boldsymbol{p}_r^{Tr}\boldsymbol{E}_l\boldsymbol{p}_l = 0, \tag{1}$$
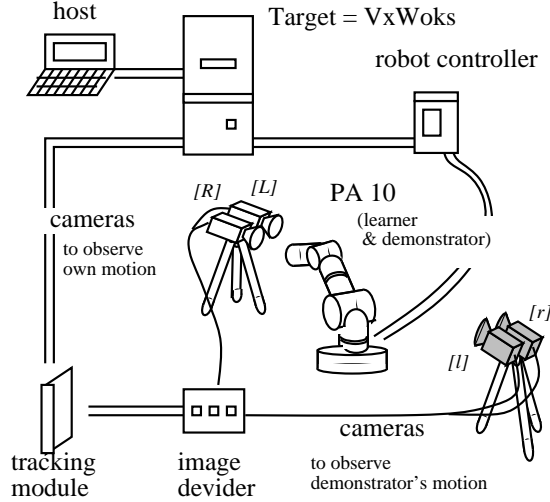
Figure 3: Experimental system

where $\boldsymbol{p}_r = [X_r \quad Y_r \quad 1]^T$, $\boldsymbol{p}_l = [X_l \quad Y_l \quad 1]^T$ and $^r\boldsymbol{E}_l$ is a 3×3 matrix representing epipolar constraints of two view points $[l]$ and $[r]$ that includes the internal and external stereo camera parameters such as focal length, image centers, and image distortion parameters. Since one of nine components of $^r\boldsymbol{E}_l$ can be determined as a scaling factor, the number of unknowns is eight. Therefore, we can determine $^r\boldsymbol{E}_l$ by observing eight points in 3-D space on the both image plane. Usually, we use the LS method to estimate $^r\boldsymbol{E}_l$ with more than eight points.
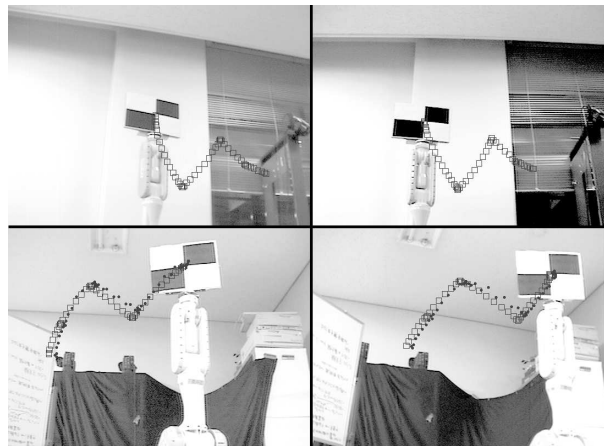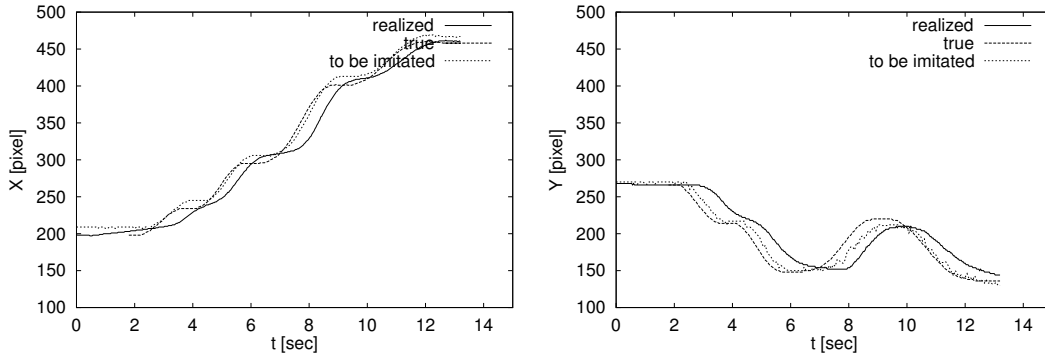
4 Experimental Results


Figure 4: Observed and desired trajectories

Fig.3 shows the experimental system where the robot arm system has two roles, that is, the demonstrator and the learner, by setting two pairs of stereo cameras ($[L]$ and $[R]$, and $[l]$ and $[r]$) for each of them. The motion trajectory observed by the learner's stereo pair is shown at the top of Fig.4 (two sequences of empty squares) and

the desired trajectory generated on the learner's view are shown at the bottom of the figure, where the empty squares and the solid circles indicate the true and generated trajectories, respectively. The starting point is the center of the checker board at the end of the robot arm (shown in the figure), and the demonstrator showed its waving motion (first downward and then upward motions).

(a) x-axis trajectories

(b) y-axis trajectories
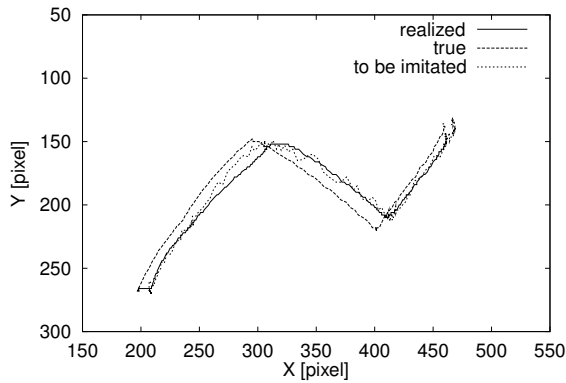
(c) close-up of the trajectories on the image plane

Figure 5: Experimental results

Figs.5(a), (b), and (c) show the experimental results of imitation by image trajectories (t-x, t-y, and x-y), respectively, each of which includes three kinds of trajectories: the realized one (a solid curve), the true one (a broken curve), and the one to be imitated that is mapped from the observed one (a dotted curve). There are two kinds of noise sources on the realized trajectories, one comes from the estimation error of epipolar constraint and the other one from AVS. The former can be seen as the difference between the true trajectory and the one to be imitated, and is not so serious since these two curve overlap each other. On the other hand, the second difference between the realized trajectory and the one to be imitated is not so small as the first one. This seemed to be caused by the delay of the control signal, and should be improved. However, the imitated motion is almost similar to the true one.

5 Discussion

The epipolar constraint can be regarded as an image transformation based on three-dimensional opt-geometrical constraint even though no 3-D reconstruction is included. Further, motion description is merely image trajectory, and no more abstraction in this level. To overcome these problems, first the learner should represent its own motion through its perception, and then try to find correspondence to the observed motion performed by the demonstrator. This is one of our future work for robot communication.

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