Imitative Interactions with Sony humanoid robot

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Experimental studies of the imitative interactions (Ito & Tani, 2004) between robots and humans were conducted by using the Sony humanoid robot QRIO SDR-4XII (see Figure 1). As the first step, adaptation of the robot was examined in the context of imitation by synchronization. The later experiment examines the case of mutual interactions.

In this experiment, the robot learns multiple movement patterns shown by a user's hand movements in the learning phase. The RNNPB shown in Figure 2 (a) learns to predict how the positions of both the user's hands change in time in terms of the sensory mapping from s_t to s_{t+1} and also it learns how to change the motor outputs correspondingly in supervised ways. The positions of the user's hands are sensed by tracking colored balls in his hands. In the interaction phase, when one of the learned movement patterns is demonstrated by the user, the robot arms are expected to move by following the pattern. When the hand movement patten is switched from one to another, the robot arm movement pattern should switch correspondingly. This sort of on-line adaptation can be done by conducting the generation and the recognition processes simultaneously as a mirror system (see Figure 2 (b)). When the prediction of the user's hand movement generates error, the PB vector is updated to minimize the error in real time while the motor outputs are generated depending on the current PB values.

The results of the experiment are plotted in Figure 3. It is observed that when the user hand movement pattern is switched from one of the learned patterns to another, the patterns in the sensory prediction and the motor outputs are also switched correspondingly by accompanying substantial shifts in the PB vector. Although the synchronization between the user hand movement pattern and the robot movement pattern is lost once during the transitions, the robot movement pattern is re-synchronized to the user hand movement pattern within several steps. The experiments also showed that once the patterns were synchronized they were preserved robustly against slight perturbations in the repetitions of the user's hand movements. Our further analysis concluded that the attractor dynamics system, with its bifurcation mechanism via the

Figure 1: A user is interacting with the Sony humanoid robot QRIO SDR-4XII.

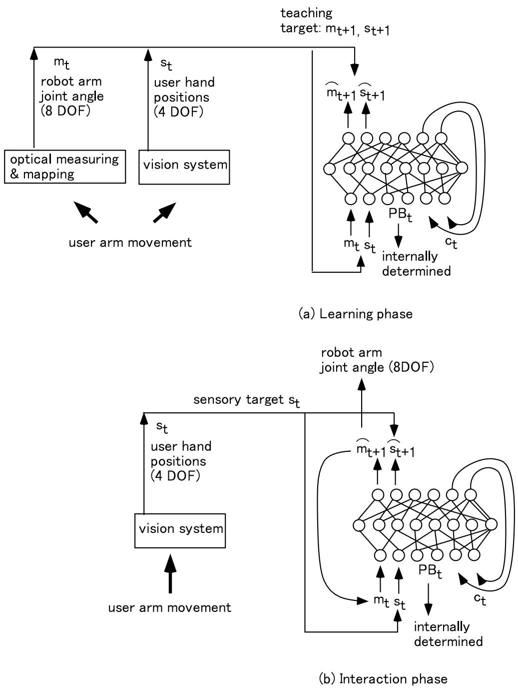

Figure 2: System configurations in learning phase (a) and interaction phase (b).

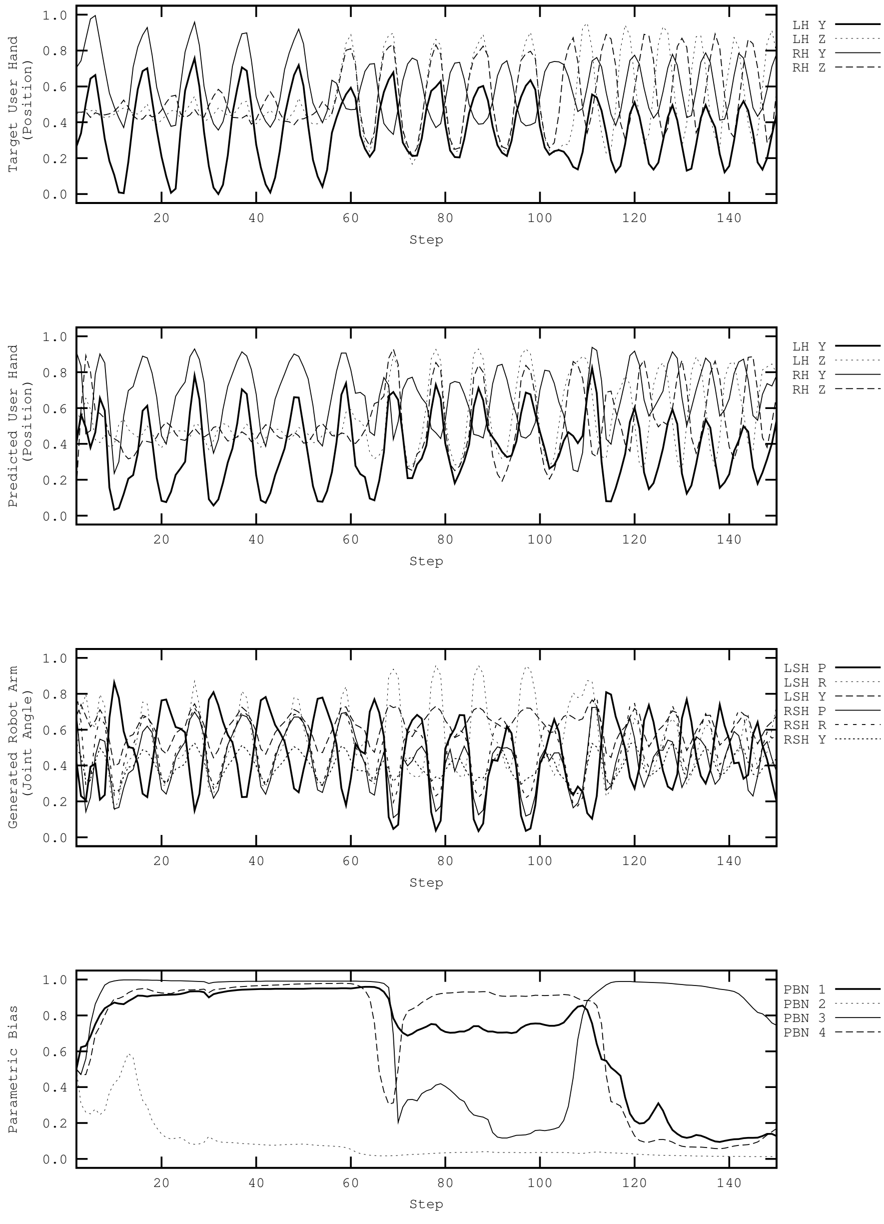

Figure 3: Switching of the robot movement pattern among three learned patterns as initiated by switching of user hand movement. User hand position and its prediction by the robot are shown in the first and the second row, respectively. The third and fourth rows show motor outputs and PB vectors, respectively.

PB, makes the robot system manipulatable by the users as well as robust to possible perturbations.

Mutual imitation game

The previous experiments focused mainly on adaptation of the robot. We conducted another experiment which focused on bi-directional adaptation in mutual interaction between the robot and users. In this new experimental set-up, after the robot learns multiple movement patterns in the same way as described previously, subjects who are ignorant of what the robot learned are faced with the robot. The subjects are then asked to find as many movement patterns as possible for which they and the robot can synchronize together by going through exploratory interactions. Five subjects participated in the experiments. Although most of the subjects could find all movement patterns by the end, the exploration processes were not trivial for the subjects.

There are interesting points in this new experiment as compared to the previous one. First, the master-slave relation, which was fixed between the subjects and the robot in the previous experiments, is no longer fixed but is instead spontaneously switched between the two sides. Second, there are autonomous shifts among synchronized patterns between the robot and the subject. Once a synchronized pattern is achieved, it breaks down after a while and then another pattern of synchronization appears. We speculate that appropriate analysis of these observed phenomena might shed a ray of light on the mechanism of joint attention (Baron-Cohen, 1996; Moore & Corkum, 1994) as well as turn-taking behaviors (Trevarthen, 1977). Although joint attention itself might be explained simply by synchronization (Andry, Gaussier, Moga, Banquet, & Nadel, 2001; Ijspeert, Nakanishi, & Schaal, 2003), a more interesting question is how joint attention to one pattern can break down and flip to another one spontaneously. How do the roles of leader and follower repeatedly switch automatically between the robot and the subject? We propose that the coexistence of stable and unstable characteristics in the system dynamics might be the main cause for the spontaneous shifts. The stability originates from the synchronization mechanisms for shared memories of movement patterns between the robot and the subjects while the instability arises from the potential uncertainty in predicting each other's movements. (The subjects cannot be completely sure about the pre-learned patterns of the robot and the robot cannot predict well the subject's own intended patterns.) Recently, Sato and Ikegami (2004) related this characteristic to the undecidability of the Turing test in the theoretical analysis of the imitation game. Further examination is required in this part of the analysis.

In the mutual interaction experiments, most of the subjects reported that they occasionally felt as if the robot had its own “will” because of the spontaneity in the generated interactions. It is speculated that the spontaneity, which arose from including users in the loop of the total system dynamics, might play an important role in attracting people to play with entertainment robots.

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