Abstract

In this study, we report the investigations conducted on the mimetic behavior of a new humanoid robot called Alter3. Alter3 autonomously imitates the motions of a human in front of him and stores the motion sequences in its memory. Alter3 also contains a self-simulator that simulates its own motions before executing them and generates a self-image. We investigate how this mimetic behavior evolves with human interaction, by analyzing memory dynamics and information flow between Alter3 and humans. One important observation from this study is that when Alter3 fails to imitate human motion, humans tend to imitate Alter3 instead. This tendency is quantified by the alternation of the direction of information flow. At the conference we will also report on the experiments we carried out recently, in which two Alters imitated each other, and in which we let people possess and imitate Alter.

System architecture

Alter3 has 43 movable air actuator axes in its body, and two cameras, one in each eye. Alter3’s internal system is a combination of Rössler’s autonomous cognitive map system (Rössler (1981)) and Frith, Blakemore, and Wolpert’s comparator model (Frith et al. (2000)). We extended it to include a memory state and a neural network as a spontaneous dynamics circuit (Fig. 1). The system is constructed with three functionalities in mind: 1) Automatic imitation capability 2) Self-simulation 3) Memory selection and variation.

Alter3 has two modes: awake mode and dream mode. In an awake mode, Alter3’s motor commands are generated by the automatic mimicry module. An image from the eye camera is taken as input to a pose detection algorithm OpenPose (Cao et al. (2017)). Based on the position of the key points of the detected pose, angles of axes are calculated. Alter3’s spontaneous dynamics consist of spiking neurons (Izhikevich (2003)) that are combined with the calculated angles of the axes as a weighted average, to calculate the final axis values. Thus, Alter3 not only imitates human motion but also modifies its own motion to an extent based on its spontaneous dynamics.

Alter3 contains a self-simulator that simulates a future self-image before executing motor commands. The predicted self-image is compared with the visual perception of the optical flow values. If the difference between the optical flow values and the predicted self-image exceeds a threshold, the mode switches from awake mode to dream mode.

Alter3 has a fixed memory size (1500 frames) in which the sequence of movements is divided into short chunks that are stored over time. Each memory chunk (consists of 30 frames) is a short sequence of behavior but is labeled by an abstract representation of the visual image (the optical flow [Farnebäck (2003)]) of the self-image) of the movement. Alter3 can replay past motions based on memory in the dream mode. It should be noted that memory recall processes are not simple replaying images. Rather, they are memory reconstructions with mutations that are caused by spontaneous dynamics. When there is no one in front of Alter3, he can call up the memory on his own and play with it. This also rewrites the patterns stored in the memory. We expect that the memory recall mechanisms will allow Alter3 to explore new movement patterns that cannot be generated from its automatic mimicry capacity.

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1Main body of this paper has been published in Front. Robot. AI (Masumori et al. (2021)).
Experiments

We conducted experiments with Alter3 at the NRW-Forum, Düsseldorff between April 26 and May 4, 2019. During the experiments, Alter3 was located in the exhibition room, (Fig. 2) which is a public space. We performed six experiments, each consisting of 100,000 frames and lasting approximately 4–5 h. During the experiments, we recorded Alter3’s motor commands, its actual motion data, and the human motion data. We analyzed these data to understand how Alter3’s behavior changed during the experiments.

Figure 2: Exhibition of Alter3 at the NRW-Forum, Düsseldorff. The public could clearly see Alter3’s motion.

Development of memory structure

We analyzed the developments in memory pattern and actual motions of Alter3, which were visualized by so called UMAP (McInnes et al. (2018)). Figure 3 shows that the clusters of the poses generated from memory (the red dots), are initially located near the clusters of the poses generated by automatic mimicry capacity (the blue dots). Then, the red clusters begin to vary and move away from the blue clusters. These results suggest that the memory selection and variation process work well to diversify memory, rather than just copy human motion.

Figure 3: Example of the time development of motion patterns.

Information flow between Alter3 and human

To evaluate whether Alter3 could effectively imitate human motion and whether humans also imitated Alter3, we used transfer entropy (TE; Schreiber (2000)) to estimate the direction of information flow. A high TE from one entity to another indicates that the former affects the latter. Thus, TE enables us to estimate causation during an imitation. We computed the TE between the motion data of both Alter3 and humans and compared the results for the awake and memory conditions. The awake condition was defined to be equivalent to the awake mode explained above. The memory condition was defined such that the memory was used to imitate human motion. Figure 4 shows that, in the awake condition, the value of TE from Alter3’s motion to human motion was significantly lower than in the opposite direction. In contrast, for the memory condition, the value of TE from Alter3 to human motion was significantly higher than the TE value for the opposite direction. This suggests that information flow was reversed in the memory condition, and humans tended to imitate Alter3.

Figure 4: Transfer entropy (TE) between Alter3 and human motions.

Discussions

Starting from primitive imitation without any memories, Alter3 develops its memories via imitating human behavior and generates various behaviors based on memory selection and variation processes. While Alter3 interacts with a human and fails to imitate the human’s behavior, humans tend to imitate Alter3 instead. This is quantified by the reversal of transfer entropy. We say that this spontaneous switching of roles between man and machine is a necessary condition of personogenesis (i.e. development of personality).

Using Alter3 and Alter2 (the older version), we recently compared the reciprocal imitation of the two autonomously programmed Alters with that of the human-possessed Alters. Even for the same task of mutual imitation, the human-possessed case shows a greater diversity of interactions than the non-possessed case. This is due to the meta-cognition that the non-possessed Alter only tries to imitate, whereas the possessed Alter knows that the other Alter is imitating you. We will also touch the point in the conference.
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References


