Mapping from Facial Expression to Internal State based on Intuitive Parenting

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Future robots entering into our daily life are expected to be endowed with the ability of sympathy. It includes the ability that the robot can associate the other's facial expression with its own internal state. On the other hand, understanding the developing process to acquire the sympathetic ability is one of the interesting mysteries in developmental psychology. Breazeal et al. proposed the developmental model in which a robot acquires the relationship between motor commands for facial expression with a caregiver through the imitation of facial expression of the caregiver during motor babbling of the robot [Breazeal et al., 2005].

In this paper, we propose another developmental model in which the facial expression of a caregiver is associated with the internal state of the robot through intuitive parenting [Papousek and Papousek, 1987]. Intuitive parenting is the usual parents' behavior in which they often mimic and emphasize their facial expression of certain emotional state presumed from their children's facial expression. This behavior is thought to help children to develop their sympathetic ability [Gergely and Watson, 1999].

Fig. 1 shows our proposed system. Our virtual robot acquires various kinds of the sensor information from the human caregiver; touch sensors (keyboards), sounds, and camera images. Such sensor information changes the internal state of the robot, which consists of two kinds of variables, independent to each other, corresponding to the arousal-sleep axis and the pleasure-displeasure axis [Russell, 1980]. These internal variables change based on the simple relaxation dynamics equations. This internal state is represented in these two dimensional space. This space is associated with the representational space of facial expression of others through the intuitive parenting communication as follow:

1. When the caregiver touches the sensors or makes a noise, the internal state of the robot changes.

2. Depending on its internal state, the robot shows facial expression. The association between the internal state and its facial expression is designed based on Yamada's method [Yamada, 1993] (Fig. 2).

3. The caregiver imitates the facial expression of the robot. The robot detects the change of the caregiver's facial expression and its internal state on the representational space, and associates these changes.

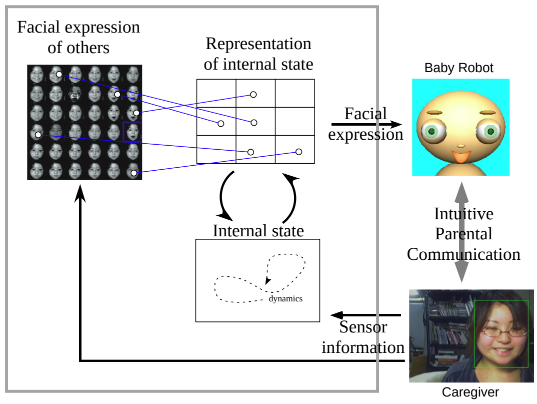

Figure 1: Associating the others' visual facial expressions with internal states

Internal state and facial expression

The internal state of the robot, $\boldsymbol{S}$, is represented by the two variables as follows,

$$\boldsymbol{S} = (p, a) \qquad \begin{cases} (-1 < p < 1) \\ (0 < a < 1) \end{cases} \quad , \tag{1}$$

where p and a indicate the levels of the pleasure and arousal, respectively. The internal state of the robot changes according to the following relaxation dynamic equations,

$$\boldsymbol{\tau}\dot{\boldsymbol{S}} = -\boldsymbol{S} + \Sigma\boldsymbol{r}_i + \boldsymbol{S}_0, \tag{2}$$

$$\Sigma\boldsymbol{r}_i = \boldsymbol{r}_e + \boldsymbol{r}_o, \tag{3}$$

where τ, $\boldsymbol{r}_e$, and $\boldsymbol{r}_o$ are the decay time constant, the effect from the external stimulus, and the effect induced by the caregiver's expression. While learning the mapping between the caregiver's facial expression and the internal state, $\boldsymbol{r}_o$ is 0.

The robot changes its facial expression according to the internal state, $\boldsymbol{S}$. The two structural variables, "curving and releasing" and "inclination", are used in out robot (Fig. 2) as proposed in [Yamada, 1993]. The former is related to the level of arousal, whereas the latter is related to the level of pleasure.

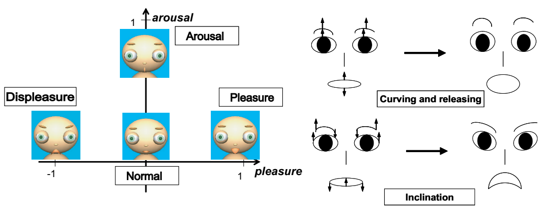

Figure 2: Internal state and facial expression

Hebbian learning

The internal state, $\boldsymbol{S}$, is represented in the representational space as the activation level of discrete nodes, $g_{kl}(\boldsymbol{S})$, which is determined as follows:

$$g_{kl}(\boldsymbol{S}) = e^{-\rho|\boldsymbol{S}-\boldsymbol{S}^r_{kl}|^2}, \quad (4)$$

where $\boldsymbol{S}^r_{kl}$ is the representational internal state of (k, l) th node. The facial expression of the caregiver is represented as the activation level of the node of self organizing map, $f_{ij}(\boldsymbol{V})$. When the facial expression, $\boldsymbol{V}$, is input, the activation level is determined as follows:

$$\begin{aligned} \delta_{ij} &= \tfrac{1}{N}\textstyle\sum_{k=0}^{N} |\boldsymbol{V}^k - \boldsymbol{V}^k_{ij}|, \\ f_{ij} &= e^{-\nu\,\delta^{\,2}_{ij}}. \end{aligned} \quad (5)$$

The connection weights between these maps, w^{kl}_{ij}, are updated by the following Hebbian learning,

$$\begin{aligned} w^{kl}_{ij}(t+1) &= w^{kl}_{ij}(t) + \Delta\, w^{kl}_{ij} \\ \Delta\, w^{kl}_{ij} &= \alpha\, f_{ij}\,(V)\, g_{kl}(S), \end{aligned} \quad (6)$$

where α is the learning rate.

Experiment

Fig. 3 (a) shows the corresponding facial expressions on the representational space of the internal state. The caregiver's faces are associated with the internal state, and the distribution is almost same as the Russell's two dimensional emotional model. Fig. 3 (b) shows the time course of the internal state variables and facial expression during the communication with the caregiver after learning. The robot changes its internal state depending on the caregiver's facial expression and successfully follows it.

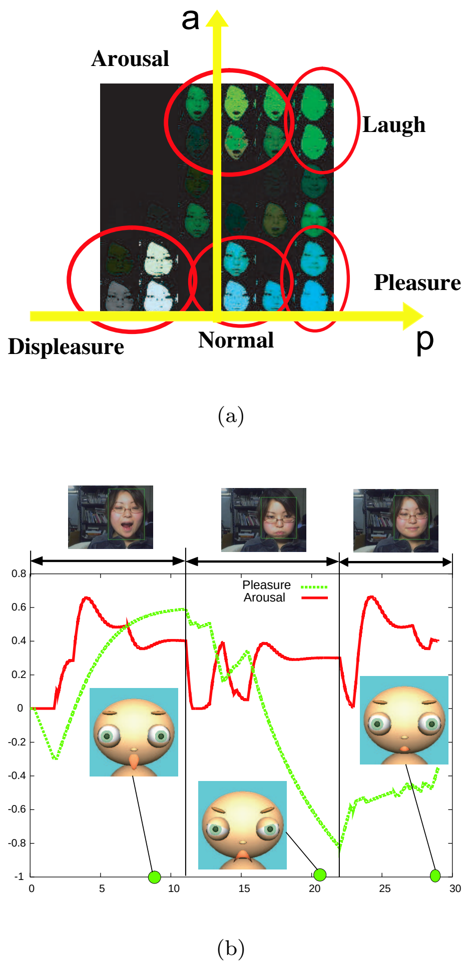

Figure 3: Experimental results: (a) Facial expressions associated with internal state, (b) Sympathetic communication after learning

References

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