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Adaptive Cooperation for Multi-Agent Systems Based on Human Social Behaviour

Hiroshi Igarashi†, Yoshinobu Adachi† and Kazunari Takahashi‡

†Department of Electronical and Electronic Engineering, Tokyo Denki University
2-2, Kanda Nishiki-cho, Chiyoda-ku, Tokyo, Japan
‡Department of Information and Computer Sciences, Saitama University
255, Shimo-okubo, Saitama-city, Saitama, Japan
Email: igarashi@isl.d.dendai.ac.jp, adachi@isl.d.dendai.ac.jp, kazu@ics.saitama-u.ac.jp

Abstract—This paper addresses a new cooperation technique based on human social behaviour for multi-agent systems. According to biological knowledges, the population contributes to the preservation of the species and adaptability of environmental variations. Multiple robot cooperation, therefore, has a potential to flexible and adaptable for task variations. Furthermore, human sociality based on others' performance evaluation is expected to enhance the total task performance. Finally, adaptability and the total performance of proposed technique are verified by pursuit problem in multi-agent system.

1. Introduction

In this paper, a new cooperation technique based on human social behaviour is proposed for practical applications by multiple robots. Most of conventional cooperation theories are divided roughly into top-down approaches and bottom-up approaches.

In the top-down approaches, motion of each robot are commanded by given rules or the supervisor. These are expected to achieve efficient performance in a particular task. However, unexpected disturbance, e.g. change of environments and mechanical failure of robots, brings about breakdown of whole systems. For the practical applications with robot cooperation, the adaptive cooperation to variations of environments and conditions is required.

On the other hand, bottom-up approaches, as observed in social beings, are expected that the population by simple individuals emergents complex and flexible organization. According to biological knowledge, the populations contribute to the preservation of the species and adaptation of environmental variations. However, individual functions are too simple for cooperative robot tasks because such social beings are only selected by struggle for survival in nature.

We focus on the human society here. Humans have not only potential of the survive but also changes themselves based on evaluation of others' performance which are physical abilities, knowledges and so on[1]. These characteristics are available for the cooperative tasks by robots. Fortunately, there are a lot of rich store of knowledge about human sociality in social psychological field.

Shiose et. al proposed a sociality in multi-agent system[2]. They defined two particular motion inputs, that is, "egoism" and "altruism". And the sociality is represented as variable weight parameters for these motion inputs, and then, change of sociality is observed. However, the modification method of sociality is based on global evaluation without concern of the total performance.

The primitive motion model in social beings, called Boids model, is utilized[3]. The Boids model is based on three forces; separation, cohesion and alignment, and the model could represent as birds flocking, swarming, fish schooling and so on. In our study, pursuit problem in MAS is also applicable the Boids model as primitive motion inputs.

In this paper, the personality of individual is described by variable weight parameters, named social parameters, on input commands; "egoism" and "altruism". The egoism corresponds to the cohesion force to targets, and the altruism is the separation and the alignment forces in the Boids model.

Furthermore, the social parameters of each individual are modified by itself with interaction on others' evaluation by applying to the knowledge of social psychology. In other words, the balance of "egoism" and "altruism" is determined depending on present environment and the system condition.

By the proposed technique, multi-agent system (MAS) is expected to perform adaptively to variation of environment and agent conditions. Finally, the adaptability and performance of the cooperation are experimented by pursuit problem in MAS.

2. Sociality of Agents

The human sociality has a potential adaptabilities similar as social beings, e.g. social insects, obtained in the process of evolution. As for the beings, populations for the species preservation have been acquired with the struggle for survival. On the other hand, in the human social construction, not only the survival but also others' evaluation as physical abilities and knowledges, are available.

In the cooperative robot tasks, the social composition should be introduced not only the struggle for survival but also evaluations of others' performance. Then, the behavioral principles of the human society are applied to the MAS, and a general cooperation technique with high adaptation to environment variation and situations is expected.

2.1. Human Social Behaviour

In this paper, three famous knowledges according to social psychology are adopted to the pursuit problem in MAS;

- The syntony to neighbors (2.1.1).
- The fundamental attribution error in others' evaluation [4][5](2.1.2).
- The charisma of the performance (2.1.3).

2.1.1. Syntony

The *syntony* is effective to keep the population. This characteristics is also observed in swarm behavior of animals.

2.1.2. Fundamental Attribution Error

The *fundamental attribution error* is required to keep diversity of individual personality. This corresponds to the mutation of GA to prevent the deadlock situation means annihilation of the species in animate nature.

2.1.3. Charisma

The *charisma* contributes to improve the task performance influenced by the agent which performs better at that time. Because of depending on environments and system conditions, the charisma agent is easy to change by the minute.

3. Motion of Agents

3.1. Pursuit Problem

In this paper, a pursuit problem with multiple preys and predators is assumed (see Fig. 1). A goal of the task is to capture the prey by predators as shown in Fig. 1(b). Preys just perform to escape from predators in sight, and predators are cooperate each other with the human social principle. Finally, the number of captured preys is evaluated as a total task performance.

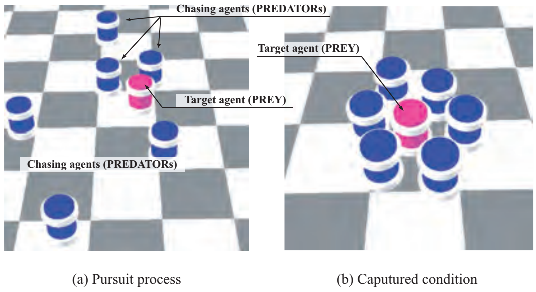

Figure 1: Multi-agent simulation task to capture the preys.

3.2. Motion Equation of Agents

In this section, the representation of an agent is mentioned. Lots of studies on MAS are described in the grid world as cellar automaton. However, it is not enough to represent the a group dynamics and an agent character. Therefore, omni-directional agents in Cartesian coordinate system are assumed.

The motion equation of the agent i, with a current position $\boldsymbol{x}_i = [x_i, y_i]^T$, is as follows;

$$\ddot{\boldsymbol{x}}_i = M_i^{-1}(-B_i\dot{\boldsymbol{x}}_i + \boldsymbol{u}_i), \quad (1)$$

$$M_i := diag(m_i, m_i), \quad (2)$$

$$B_i := diag(b_i, b_i), \quad (3)$$

where, $\boldsymbol{u}_i \in R^2$ is input force to the agent i. Then, m_i and b_i are mass and viscous of the agent i, respectively.

Note that, mass and viscous are set randomly in the experiment to verify a generally of the proposed technique.

3.3. Definitions of Predators' Input Forces

The individual personality of predators is described as social parameters for egoism forces and altruism forces. As shown in Fig. 2, each agent has finite field of view and the input forces are calculate with the visible agents. A vector of input force is represented as composition of the egoism $\boldsymbol{u}_i^E$ and the altruism $\boldsymbol{u}_i^A$.

The egoism forces $\boldsymbol{u}_i^A$ are generated by attractive forces from the visible preys and their COG $\bar{\boldsymbol{x}}^p$. On the other hand, the altruism forces $\boldsymbol{u}_i^E$, which is to prevent from making collision, are repulsive forces from visible predators and COG of the predators $\boldsymbol{x}_c$, and additionally a syntony force to neighboring velocity $\dot{\boldsymbol{x}}_c$ on human sociality mentioned in the section 2.1.1.

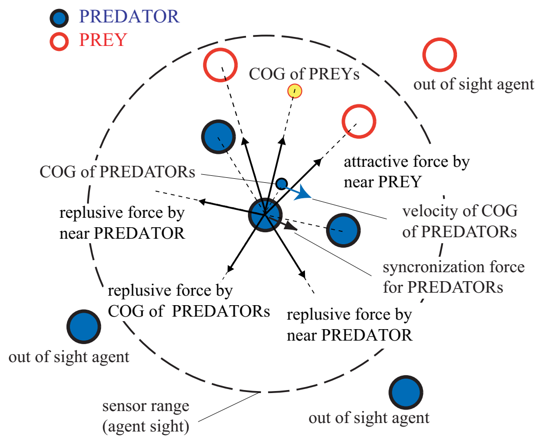

Figure 2: Input force definitions for each agent.

These forces are represented as follows;

$$\boldsymbol{u}_i = \boldsymbol{u}_i^E + \boldsymbol{u}_i^A, \tag{4}$$

$$\boldsymbol{u}_i^E := \mu_i^e \left(\sum_{j \in \Omega_i} \frac{(\boldsymbol{x}_j^p - \boldsymbol{x}_i)}{|\boldsymbol{x}_j^p - \boldsymbol{x}_i|} + (\bar{\boldsymbol{x}}^p - \boldsymbol{x}_i) \right), \tag{5}$$

$$\boldsymbol{u}_i^A := -\mu_i^a \left(\sum_{j \in \Omega_i} \frac{(\boldsymbol{x}_j - \boldsymbol{x}_i)}{|\boldsymbol{x}_j - \boldsymbol{x}_i|} + \frac{(\boldsymbol{x}_c - \boldsymbol{x}_i)}{|\boldsymbol{x}_c - \boldsymbol{x}_i|} \right) + \mu_i^s \dot{\boldsymbol{x}}_c, \tag{6}$$

where, Ω_i denotes a set of indexes of visible agents from predator i, and $\boldsymbol{x}_j^p$ is a position of the prey j. μ_i^e, μ_i^a and μ_i^s are weight parameters, named social parameters, for the attractive force, the repulsive force and the syntony force, respectively. These parameters represent the agent personality modified by interactions during the task.

3.4. Performance Evaluation of Predators

The performance evaluation of a predator is described here since human sociality is based on evaluation of others unlike the social beings. In a pursuit problem, a predator should be approach preys and inhibit the deadlock condition. Therefore, the evaluation value about task achievement of predator i, η_i^A, is calculated by following equation;

$$\tau_A \dot{\eta}_i^A = \begin{cases} \frac{c_i+1}{d_i^p} - \mu_A c_i \eta_i^A & d_i^p < s_R \\ \frac{c_i+1}{s_R} - \mu_A c_i \eta_i^A & otherwise \end{cases} \tag{7}$$

where, c_i denotes the number of captured preys by the predator i and τ_A represents the time constant. Then, d_i^p and s_R are distance from the nearest prey and maximal visible distance, respectively.

The predator, which keeps high performance η_i^A, is respected by other predators and has impacts to them. Note that, the charisma can be changed easily during the task because the performance depends on environment conditions. This therefore contributes to the high adaptability in MAS cooperation.

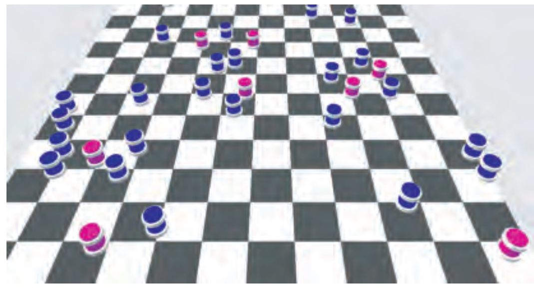

Figure 3: Experimental view: multiple preys pursuit task.

3.5. Modification of Social Parameters

A key of proposed cooperation technique is modification of the social parameters by interactions. This modification is based on human sociality mentioned in the section 2.1.3 and 2.1.2. A vector of social parameters of agent i, $\boldsymbol{s}_i^p = [\mu_i^e,\ \mu_i^a,\ \mu_i^s]^T$ is calculated in each time step as follows;

$$\tau_s \dot{\boldsymbol{s}}_i^p = \sum_{j \in \Omega_i} (1 + \gamma_e \epsilon)(\eta_j^A - \eta_i^A)(\boldsymbol{s}_j^p - \boldsymbol{s}_i^p) \tag{8}$$

$$- \mu_v (\boldsymbol{s}_i^p - \boldsymbol{s}_0), \tag{9}$$

where, τ_s denotes the time constant and μ_v and γ_e are a weight to prevent divergence and a random value, respectively. γ_e is to simulate the attribution error to evaluate others' performance, and ϵ is random value, $-1 < \epsilon < 1$. As mentioned in 2.1.2, the error contributes to keep variety of predators' personality for high adaptation.

And $\boldsymbol{s}_0$, with $[0.5,\ 0.5,\ 0.5]$, is a vector of standard values of social parameters. By this equation, if a visible predator from a predator i has higher achievement evaluation η^A, then the predator i modifies its social parameters to approach the higher predator. This corresponds to charisma described in the section 2.1.3.

4. Experiment and Results

Adaptability and performance of proposed cooperation technique are verified with pursuit problem in MAS. As shown in Fig. 3, multiple predators attempt to capture the multiple preys in the toroidal world. Capturing is required three or more predators to prevent escape of the prey and capturing count c_i of involved predators is incremented. The captured prey is disappear once, and then, the prey is reallocated in random position.

4.1. Experiment Setup

In the experiment, the number of predators and preys are 20 both. To represent the environment variation, the field sizes are 16×16, 20×20, and 24×24, respectively, where diameter of each agent is 1 and radius of field of view $s_R = 5$. Furthermore, slope of the environment is considered with 0, 3 and 6 degree, in each size of the field. By the variation of environments, suitable balances of the egoism and the altruism are also change. The initial social parameters μ_i^e, μ_i^a and μ_i^s are determined at random from 0.1 to 0.9.

4.2. Experiment Results

The evaluation of the task is how many preys are captured in 5000 calculation steps. And the trail is carried out 20 times in each environment and three algorithms which are without sociality, with sociality but $\gamma_e = 0$ and $\gamma_e = 0.3$. As shown in Fig. 4(a), the number of captured preys are decrease as growing the field size and slopes.

In the small field, 16×16, preys are captured well without sociality, however, in the large field with the slopes, the sociality modification works to improve the capturing performance. Furthermore, by Fig. 4(b) and (c), social parameters for the egoism and the altruism increase as the field size and the slopes. We suppose these tough environment requires large input forces to capture the preys, then succeeded predators also have such characteristics and others are influenced.

4.3. Conclusions

In this paper, a new cooperation technique based on human social behaviour is proposed. The cooperation technique is classified as the bottom-up approach including others' evaluation unlike social beings. By the algorithm for modifying social parameters considering others' evaluation, the cooperation achieves high adaptability and performance.

By the experiment results, the technique improves the task performance in tough environment, large field or slopes. However, the performance in small field is not enough. In the future work, the performance enhancement in the simple environments and analysis of individuals are necessary.

Acknowledgments

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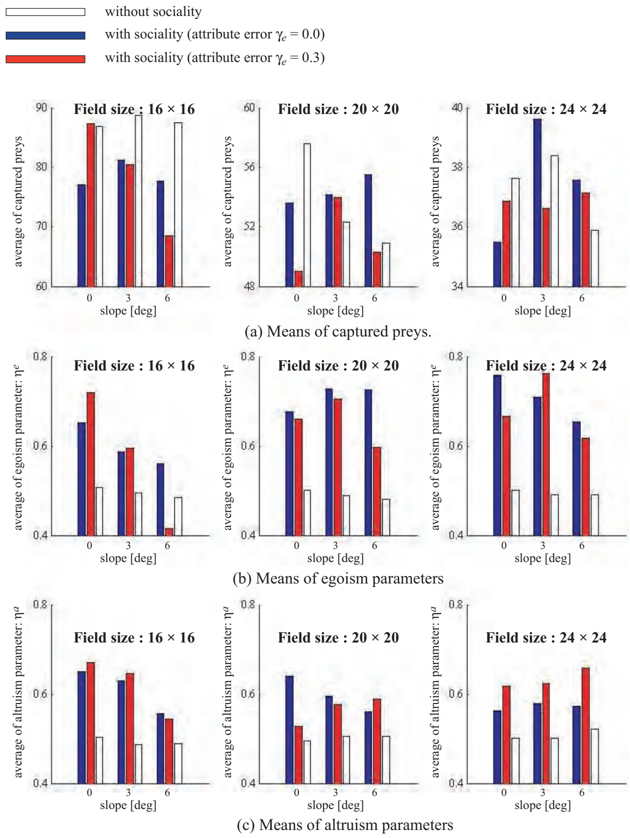

Figure 4: Experimental results: multi-PREY capturing task.

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