The Belief-Desire-Intention Architecture of Sincere Software Agent Environment

Nur Huda Jaafar [1], Azhana Ahmad [2], Mohd Sharifuddin Ahmad [2],
Nurzeatul Hamimah Abd Hamid [3]

[1]*Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA Cawangan Johor,*
Kampus Segamat, Jalan Universiti Off KM 12, Jalan Muar, 85009 Segamat, Johor, Malaysia
[2]*College of Computing and Informatics, Universiti Tenaga Nasional, Putrajaya Campus,*
Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia
[3]*Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA Shah Alam,*
40450 Shah Alam, Selangor, Malaysia

Abstract – **Software agent is autonomous technology that helps a lot the human being in performing the task. The capability of agent to take actions on behalf of human is one of the reasons why researchers or developers of autonomous systems adapt the human characteristics either in the form of physical or behaviours. Sincerity is one of ethical human behaviour that can be instilled in software agent environment system. To instil the ethical behaviour such as sincerity, the belief-desire-intention (BDI) architecture should be designed. This paper explains the BDI architecture for sincere software agent environment system during performing task.**

Keywords – **Software agent, Multi - agent system, Belief-Desire-Intention, Sincerity, Architecture.**

1. Introduction

Software agent is the technology that supports autonomous systems.

The article is published with Open Access at www.temjournal.com

This technology has been proven for its capability to be an assistant to human in various fields such as health, education, military and manufacturing [1], [2] either individually or in a group known as multi-agent. To strengthen the role of agent as an assistant to human, many researchers and developers of software agent adapt human behaviour in their autonomous system. Most of them use this way to reduce the agents from taking irrational actions during making decisions.

Sincerity is one of ethical human behaviour that can be considered as an item to be instilled in software agent environment. Human organizations have shown that this ethics can bring positive impact on organization, especially when teamwork is involved in performing task [3], [4]. To instil the human sincerity behaviour into software agent environment, the human sincerity factors [5] and the characteristics of software agent have to be studied.

One of the important characteristics in software agent is how it can react to its environment rationally. Belief-Desire-Intention (BDI) model is known as an established practical reasoning in software agent that is similar to humans' practical reasoning. This paper will explain the BDI architecture for sincere software agent environment. Before discussing the BDI architecture of sincere software agent environment, this paper will introduce the related papers which are related to the sincere agent environment. Then the BDI architecture for sincere agent environment will be discussed in depth before we conclude the paper.

2. Related Works

a) *Multi-agent System (MAS)*

Software agent is one of the artificial intelligence fields [6], [7] that has been used widely to support the autonomous systems in various fields such as

healthcare [8], [9], military [10], [11] and learning [12]. Its characteristics such as responsive, proactive, goal-oriented, reactive and learning capabilities shows that it is viable to be an intelligent assistant to humans being. A software agent can work individually or in a team. Kamdar, Paliwal and Kumar [13] highlighted the usefulness of MAS. It can solve many complex applications:

i. MAS supports the construction of robust, flexible, and extensible systems.
ii. Its architecture is fitted with a distributed system environment that rely on local information and decision making.
iii. Its flexibility characteristic is able to change the system and heterogenous types of agents.
iv. The awareness towards its environment enables the MAS to give quick response and adjust to faults.

b) Instilling Human Behaviour in MAS

The ability of agents to make decisions on behalf of humans is the reason why many agent developers or researchers study human behavior to be adapted in the MAS. They study ethical behaviour of human and instill it in multi-agent environment to reduce unethical behaviour that may exists while the agent is taking actions on behalf of human [1], [14], [15].

Adapting human in multi-agent environment is also one way to design autonomous systems that are more user-friendly with humans. Previous research shows that adapting human behaviour in multi-agent environment bring many benefits to human lives [2], [16].

Sincerity is one of human ethical behaviour that can be considered as another useful item to be instilled in multi-agent environment. It has been proven in human organizations that it can alleviate selfishness in performing tasks and increase the productivities among the team members [3], [4], [17].

As such, the benefit gained from sincere behaviour can also be considered as an added element to be utilized and instilled in multi-agent environment. However, the architecture of multi-agent environment should be designed properly in order to ensure that it can be fitted when instillation takes place. The mechanism ensures that it can work well, and the same has to be studied.

c) Belief-Desire-Intention

Rationality is an important element to influence agent to choose the right actions whenever it responds to its environment. According to Russel and Norwig [18], rationality that arises in agent are based on four things:

- The performance measures the success criterion;
- Prior knowledge of an agent towards its environment;
- The action that the agent can perform;
- The sequence of agent's perception to date.

Belief-Desire-Intention (BDI) is a model that supports an agent to be a rational one. It is known as the best architecture in modeling practical reasoning which is similar to humans' practical reasoning [19], [20]. There are three main components of BDI structure: (1) Beliefs that represent an agent's internal knowledge about the world, (2) Desires that show the objectives the agent attempt to accomplish and (3) Intentions that refer to the current preferred action plan.

Many applications based on software agent technology that involve complex and dynamic environment use the BDI architecture [21]. Besides turning on the rationality in the agent, the BDI also supports the agents' autonomous capability by enabling the agents to select tasks based on their beliefs and decide the suitability of needed actions in order to perform the tasks [22].

3. The Architecture of Sincere Agent Environment

A Sincere Agent Architecture represents an overview of a sincere agent environment. We develop the architecture of sincere agent environment based on our analysis of human organization in performing the tasks as shown in Figure 1. This architecture comprises of three main components to enforce the instilling of sincerity behaviour in an agent environment: (i) agent community, (ii) workload manager and (iii) sincerity evaluator.
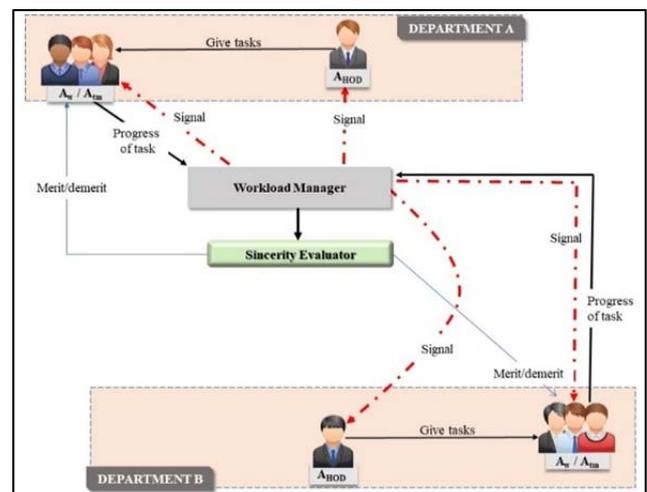

Figure 1. The Architecture of Sincere Agent Environment

(i) Agent Community

Agent community consists of three types of agents: (i) Head of department agent; A_{hod}, (ii) Worker agent; A_w and (iii) Teammate agent; A_{tm}. The highest rank in agent community of sincere agent environment is the A_{hod}.

As the highest rank in the agent community, the A_{hod} will observe the work progress of all agents under its supervision. It also has authority to issues the orders to its agents to do any tasks; either a new task or a task taken over from teammate agent. The A_{hod} also has capability to make decisions, which means it allows or denies its agents in giving help to the agents from other departments.

Worker agent, A_w, and Teammate agent, A_{tm}, are the agents under the supervision of A_{hod}. They are responsible to the agents to perform tasks as scheduled. Both bear the same responsibility and authority. As teammates, both (A_{tm} and A_w.) need to collaborate in certain situation to accomplish the given task.

(ii) Workload Manager

A Workload Manager is used to monitor the performance of all agents in a sincere agent environment during completing their tasks. It is able to:

a) Control when an A_w is allowed to get help from the A_{tm}.
b) Control when an A_w can offer help to its A_{tm}.
c) Evaluate the capability of an A_w to have another task.

The Workload Manager enforce these roles based on the evaluators requirements that are embedded in the Workload Manager. There are five types of evaluators in the Workload Manager:

a) *Permission of Getting Favour Evaluator (Fav)*
It is the evaluator that decides the right time for an agent to be allowed to get help from a teammate.
b) *Workload Calculator (W)*
The Workload Calculator measures the weightage of workload carried out by an agent. It determines the status of agent whether it is having a heavy or normal workload.
c) *The Progress of Aw's Current Tasks (PT_c)*
This evaluator identifies the capability of A_w to complete all its tasks on schedule while at the same time handling its teammate's task.
d) *Job Scope-Experience Evaluator ($JS - E$)*
Job Scope-Experience Evaluator evaluates the job scope of an agent and experience of the agent.
e) *Priority Management (PM)*

The priority measurement evaluates the priority of the tasks that A_w needs to perform.

These evaluators evaluate each agent based on the task progress of the agent. The signal received by the agents is based on the results of the evaluators. The results will then be the inputs to the sincerity evaluator.

(iii) Sincerity Evaluator

Sincerity evaluator is used to rank the sincerity level of each agent. The sincerity evaluator can do the following activities:

- Predict a possible merit point which A_w may get from performing a task.
- Calculate the actual merit point after the A_w completes a task.
- Calculate the cumulative sincerity merit point.
- Consider a demerit point if the A_w issues as blaming or bragging message.
- Calculate and rank the sincerity level of A_w.

The sincerity level issued by sincerity evaluator influences the A_w in reacting towards its A_{tm}'s situation while performing the tasks.

4. The Architecture of Belief-Desire-Intention for Sincere Agent Environment

In a sincere agent environment, the BDI architecture is used to make the agent react to its environment and goals rationally. The BDI architecture for a sincere agent environment is shown in Figure 2. The status of the BDI of sincere agent is based on the environment of sincere agent, Env. The Env has a pre-assessment function and a certain scenario that contribute to the state of the agent's belief. A scenario is the way the agents, A_w, A_{tm} and A_{hod} interact in order to achieve the goal in completing a task. The pre-assessment refers to the evaluators in the Workload Manager.

We define the environment pre-assessment, Env_{pre} as:

$$Env_{pre} \rightarrow (Fav \cup W \cup JS - E \cup PT_c \cup PM)$$

While Env which influences the agent's belief consists of:

$$Env \rightarrow (A, Sce, Env_{pre}) \text{ , in which}$$

A is a set of agents that consists of A_{hod}, A_w and A_{tm} that are involved in a certain scenario, Sce, that can influence the agent's belief. However, before an agent takes any action, the agent has to fulfill the Env_{pre}.

The Belief, B, represents the state of the environment conditioned by a belief revision function, brf, of the agent. The agent's belief is influenced by the Env and the agent's sincerity level,

S_{level}, which is based on the cumulative merit points. The characteristic of S_{level} is dynamic at either the most sincere, moderate sincere or less sincere levels. The S_{level} changes based on the percentage of the cumulative merit point earned by the agent. Blaming or bragging behaviour causes the percentage of the cumulative merit point to decrease, while the action to perform the task without any condition and completed on schedule, either its own task or the task from its teammate, increase the percentage. The belief, B, in the sincere agent environment is formulated as follows:

$$B: brf\ (Env\ \times\ S_{level}) \rightarrow \partial T$$

Where ∂T = action taken for T_i.

The agent's desire, D, is represented by the set of tasks the agent can perform based on its belief. In a sincere agent environment, the agent's desire consists of a set of pre-compiled tasks, T, which the agent can perform, which can be any of the following tasks, τ_i, depending on the current state of environment and its belief:

- τ_1: If the sincerity level is at most sincere, the agent accepts the request without putting any condition although the goal or job scope is not the same as its own.
- τ_2: If the sincerity level is at moderate sincere, the agent accepts the request without putting any condition, if the goal or job scope is the same as its own and the priority of T_i > the priority of T_c.

- τ_3: If the sincerity level is at moderate sincere, the agent accepts the request with certain conditions, if the goal or job scope is the same as its own and the priority of T_i < the priority of T_c.
- τ_4: If the sincerity level is at less sincere, the agent accepts the request without putting any condition, if the goal is the same as its own and the level of priority of T_i > the priority of T_c.
- τ_5: If the sincerity level is at less sincere, the agent accepts the request with certain conditions, if the goal is the same as its own and the priority of T_i < the priority of T_c.
- τ_6: If the sincerity level is at moderate sincere, the agent rejects the request if the goal and job scope is not the same as its own.
- τ_7: If the sincerity level is at less sincere, the agent rejects the request if the goal is not the same as its own.
- τ_8: If the sincerity level is at most sincere, the agent offers help without any condition, although the goal or job scope is not the same as its own.
- τ_9: If the sincerity level is at moderate sincere, the agent offers help without any condition, if the goal or job scope is the same as its own and the priority of T_i > the priority of T_c.
- τ_{10}: If the sincerity level is at moderate sincere, the agent offers help with certain conditions, if the goal or job scope is the same as its own and the priority of T_i < the priority of T_c.
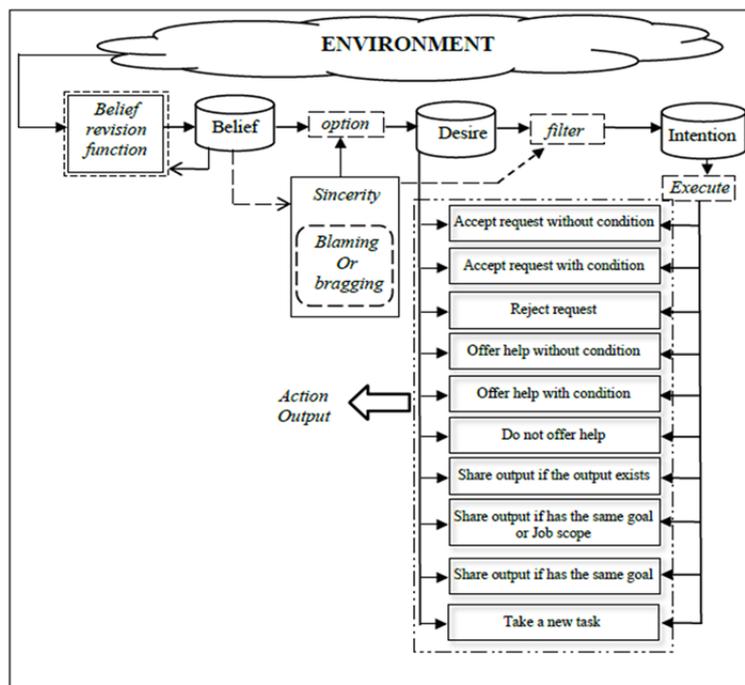

Figure 2. The Architecture of BDI for Sincere Agent Environment

- τ_{11}: If the sincerity level is at less sincere, the agent does not offer help to its teammate.
- τ_{12}: If the sincerity level is at most sincere, the agent shares the output without concerning with the goals or job scopes as long as the requested output exists.
- τ_{13}: If the sincerity level is at moderate sincere, the agent only shares the output, if the goals or job scope of the teammate is the same as its own.
- τ_{14}: If the sincerity level is at less sincere, the agent only shares the output, if the goals of the teammate is the same as its own.

- τ_{15}: The agent takes a new task ignoring the level of sincerity as long as the previous the task does not belong to its teammate.

The task selected by the agent based on its belief and desire represents its intention, I. I is a function of the environment, the sincerity level and the set of pre-compiled tasks that implies the selected task, τi from T. Then, the agent commits itself to the task which leads to the achievement of its goal. We implement a filter function to formulate the selection of task based on the level of sincerity and the set of pre-compiled tasks, T, as:

$$I : filter\ (Env, S_{level}, T) \rightarrow \tau_i, \text{where } i \geq 1$$

We represent the whole BDI process with the following pseudocode:

```
B ← B₀;          //initial beliefs
I ← I₀;          //initial intentions
while true
do
        Bc ← brf(Env);
        B ← brf (Ix (B ∪ Bc ));
        D ← options (B, D, I);
        I ← filter (B, D, I);

if duration = TRUE && (Signal of Agent's
status = TRUE || Permission from
A_hod = TRUE || Insruction from A_hod = TRUE)

        B ← brf (I, B);
        D ← options (B, I);
        I ← filter (B, D, I);
T ← execute (I. Act);
End_while
```

5. Conclusion

The rational actions from the agent are very important as an assistant tool to human being because it influences to a certain result especially during performing the tasks that involve complex situation. BDI model is one of the famous architectures in modeling practical reasoning for software agent environment. Its ability to model the practical reasoning that similar to humans' practical reasoning practice is the reason why it is used in developing autonomous systems especially if it is involving the adaption of human behaviour such as sincerity behaviour in the autonomous environment.

This study develops the BDI architecture for sincere software agent environment. It is important to formulate the belief, desire and intention of agent in sincere software agent environment in order to ensure it can react rationally while performing tasks and to avoid negative impact on human environment systems. The correct modeling of BDI also can make the sincere agent environment working dynamically.

Acknowledgements

References

[1]. Segun, S. T. (2021). From machine ethics to computational ethics. *AI & SOCIETY*, *36*(1), 263-276.

[2]. Misselhorn, C. (2020). Artificial systems with moral capacities? A research design and its implementation in a geriatric care system. *Artificial Intelligence*, *278*, 103179.

[3]. Herman, H., & Idris, J. (2019). Implementasi Model Supervisi Berbasis Keikhlasan Dalam Peningkatan Kinerja Guru Pai Di Smp Negeri Kabupaten Nagan Raya. *At-Tafkir*, *12*(2), 168-184.

[4]. Dato'Mansor, Z., & Jaharuddin, N. S. (2020). Exploring intrinsic motivation and knowledge sharing from the perspective of Islamic teaching. *International Journal of Business and Society*, *21*(1), 334-352.

[5]. Jaafar, N. H., Basir, N. M., Ahmad, M. S., & Ahmad, A. (2014, November). Human sincerity factors for adaptation in software agents. In *2014 IEEE International Conference on Control System, Computing and Engineering (ICCSCE 2014)* (pp. 223-226). IEEE.

[6]. Garro, A., Mühlhäuser, M., Tundis, A., Baldoni, M., Baroglio, C., Bergenti, F., & Torroni, P. (2018). Intelligent agents: Multi-agent systems. *Encyclopedia of Bioinformatics and Computational Biology: ABC of Bioinformatics*, *315*.

[7]. Magill, K., & Erden, Y. J. (2012). Autonomy and desire in machines and cognitive agent systems. *Cognitive Computation*, *4*(3), 354-364.

[8]. Al-Sakran, H. O. (2015). Framework architecture for improving healthcare information systems using agent technology. *International Journal of Managing Information Technology*, *7*(1), 17.

[9]. Smarsly, K., & Law, K. H. (2018). *Advanced Structural Health Monitoring Based on Multiagent Technology*. In Computation for Humanity (pp. 118-149). CRC Press.

[10]. Deshmukh, A. V., McComb, S. A., & Wernz, C. (2017). Agents as collaborating team members. In *Macrocognition in Teams* (pp. 107-125). CRC Press.

[11]. Goodwin, G. F., Blacksmith, N., & Coats, M. R. (2018). The science of teams in the military: Contributions from over 60 years of research. *American Psychologist*, *73*(4), 322.

[12]. Canbek, N. G., & Mutlu, M. E. (2016). On the track of artificial intelligence: Learning with intelligent personal assistants. *Journal of Human Sciences*, *13*(1), 592-601.

[13]. Kamdar, R., Paliwal, P., & Kumar, Y. (2018). A state of art review on various aspects of multi-agent system. *Journal of Circuits, Systems and Computers*, *27*(11), 1830006.

[14]. Lindner, F., & Bentzen, M. M. (2017, March). The hybrid ethical reasoning agent IMMANUEL. In *Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction* (pp. 187-188).

[15]. Yokoi, R., & Nakayachi, K. (2020). Trust in autonomous cars: exploring the role of shared moral values, reasoning, and emotion in safety-critical decisions. *Human factors*, 0018720820933041.

[16]. Nahavandi, S. (2017). Trusted autonomy between humans and robots: Toward human-on-the-loop in robotics and autonomous systems. *IEEE Systems, Man, and Cybernetics Magazine*, *3*(1), 10-17.

[17]. Rahman, A. (2017). Kualitas Kehidupan Kerja; Suatu Tinjauan Literatur Dan Pandangan Dalam Konsep Islam. *Jurnal Ilmiah Cano Ekonomos*, *6*(1), 7-22.

[18]. Russell, S., & Norvig, P. (2016). Intelligent Agents. In Artificial Intelligence A Modern Approach (pp. 34–61). Essex: Pearson Education Limited.

[19]. Rao, A. S., & Georgeff, M. P. (1995, June). BDI agents: From theory to practice. In *Icmas* (Vol. 95, pp. 312-319).

[20]. Wooldridge, M. (2003). *Reasoning about rational agents*. MIT press.

[21]. Logan, B. (2018). An agent programming manifesto. *International Journal of Agent-Oriented Software Engineering*, *6*(2), 187-210.

[22]. Mostafa, S. A., Ahmad, M. S., Mustapha, A., & Mohammed, M. A. (2017). A concise overview of software agent research, modeling, and development. *Software Engineering*, *5*(1), 8-25.