2019 12th Asian Control Conference (ASCC)
Kitakyusyu International Conference Center
Japan, June 9-12, 2019

Broadcast and Event Triggered Distributed Consensus Controller for Multi Agent Motion Coordination Systems

Nohaidda Sariff, and Zool H. Ismail, *Senior Member, IEEE*

Abstract - **This paper integrates a multi-agent broadcast controller with an event triggered distributed controller to solve multi agent motion coordination consensus issue. The broadcast controller has been designed by using the Simultaneous Perturbation Stochastic Algorithm. A distributed consensus protocol is adopted with an event triggering function to achieve local consensus among agents with a less number of communication channel usage. Each agent will receive a feedback signal from broadcast controller to update its position from the target while the communication between agent and its neighbours will happen if satisfying the event triggered condition at event instant time. It has been proven that the system can achieve consensus by utilizing the proposed control method. This result shows that at a certain time and iteration the agent can reach the target while reducing the communication channel usage as well as utilization of energy consumption during the process.**

I. INTRODUCTION

Motion coordination became an issue in multi-agent research area due to the substantial contributions of multi-agent in many industrial applications. Many researchers have contributed in this area in solving the control and communication problems for the groups of homogenous or heterogeneous agents. Formation [1, 2], consensus [3-6], containment [7-10] and task allocation [11, 12] are some of the examples of control issues of multi-agent robots system [13]. Consensus is one of the issues that had attracted researcher's attention over the past few years to ensure that the agents can find an agreement to reach certain quantities of interest. The main issue in consensus is in designing a suitable consensus control protocol either for global or local consensus which can guarantee the agreements between the robots to reach certain tasks or certain states can be achieved. Thus, there are a large number of interests concerning in designing a suitable consensus control protocol for homogenous and heterogeneous agents. It can be classified into a leader following consensus[14], leaderless consensus [3, 6, 15, 16], positional consensus problem [4, 17], leaderless output consensus problem [5, 18, 19] and leader-follower output consensus problem [5, 14, 19-21], (to name a few), have been intensively studied by researchers recently [22, 23].

In solving consensus in a mixed environment (broadcast and communication), Azuma [13] has proposed a "group to group" and "agent to agent" controller which had been successfully proven in achieving consensus. By combining between broadcasts (agent to all agent) and communication (agent to agent) have been proven effective in terms of convergence time and iteration compared with only one control system, thus this environment has been selected in this research study. This research is an extension of Azuma research [13] but investigates into practical aspect of communication issue among agents. An event triggered communication strategy is adapted into agent distributed controller to improve the utilization of channel during communication occur which makes this research unique.

In general, event based control is refers to a control system which is based on certain event, i.e the event or also known as transmission of signal to the controller and actuator will happen only when the measurement error of sensor is satisfied or violated certain threshold value. There are various types of event triggering protocols that had been applied by previous researchers into their control systems. R. Socas et al [24] have applied in their mobile robots navigation controller (centralized) where else L. Zhang et al [25] were applied in their mobile robot formation control (distributed) which can reduce the utilization of channel while saving the bandwidth, resources and energy. With the advantages of event based control or also known as event triggered control, it has been applied in solving multi-agent consensus. Since the agent has to interact with its neighbour continuously, while reaching consensus, thus the idea to apply event triggered in consensus control arises. As a result, the signal will be sent to the controller for update only during event instant and not continuously sent every time the sensors samples its data as happened in the conventional time triggering system. Thus, it is widely accepted that the event triggered strategy can be

Nohaidda Sariff is with the Robotics Research Group, Centre of Artificial Intelligence and Robotics, Malaysia Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia (phone: +603 2203 1495 ; fax: +603 2697 0815; e-mail: nohaiddasariff@yahoo.com).

Zool H. Ismail is with the Robotics Research Group, Centre of Artificial Intelligence and Robotics, Malaysia Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia (phone: +603 2203 1495; fax: +603 2697 0815; e-mail: zool@utm.my).

implemented to solve a consensus problem which can reduce the utilization of communication channel, bandwidth and saving computation resources.

In this paper, an event triggered control is applied into an agent controller where the agent will update its own state and its neighbours state during event instant while finding a local consensus among agent in the groups. The event triggering function has been designed so that the agent will only update its control signal if it satisfy certain threshold value during event instant. During this event, the control signal obtained from agent to agent communication is combined with a control signal from Simultaneous Perturbation Stochastic Algorithm (SPSA) to determine the deterministic movement of agent during event instant. As a results, the utilization of communication channel as well as energy consumption has been reduced during multi agent motion coordination consensus process. The main contribution of this paper are a) adaptation of event triggered communication control strategy into agent distributed controller in broadcast controller; b) the investigation of agent performances in terms of time, iteration, convergence rate and the number of channel involved in finding consensus in a mixed environment with event triggered control and c) observation of the dynamics of agents/trajectory while reaching the target with a new consensus controller.

This paper is organized as follows: Section II introduces some preliminaries that are used in this paper. The consensus problems and related work are stated and highlighted in Section III. Section IV explains the proposed control method for consensus. Section V addresses the main results of this paper that illustrates the effectiveness of the proposed control strategy in simulation studies. Finally, a conclusion is presented in the last section.

II. PRELIMINARIES

A. System Description

Assume that the feedback system as shown in Fig.1. There are a number of agents, N_i with a broadcast controller as a global controller, G and distributed event based controller as a local controller, L_i. The physical dynamics or linear discrete time model of agent i is as shown in (1)

$$A_i{:}x_i(t+1) = x_i(t) + u_i(t) \quad (1)$$

where A_i is agent $i = \{1,2,3, \dots\dots\dots N\}, x_i(t) \in R^n$ is state position of agent, $x_i(t) \in R^{nN}$ represents the group position (collective of agents) is denoted as $[x_1^T, x_2^T, x_3^T, \dots\dots\dots..]$, $u_i(t)$ is the control input and $t \in N$ is given as a discrete time. It is assume that agent i will has its own neighbour set $j \in N_i$ which is connected as undirected graph with respect to a certain radius, r.

In this system, the agent moves in n −dimensional space to reach its target/destination based on the broadcast global information and local communication via agent i interaction with its neighbour, j. Global controller, G will measure the degree of achievement of the agent performances in reaching the target, $G = J(x(t)) \in R_+$. The local controller, L_i will determine the local movement of the agents based on relative position of agents i.e. $\{x_i - x_j\}$, and the output of broadcast signal $w(t)$. Each agent will update its own state, x_i and its neighbours state, x_j when the event triggered condition, ETC is violated. The agents will then determine its motion to the target point continuously until the consensus is achieved.

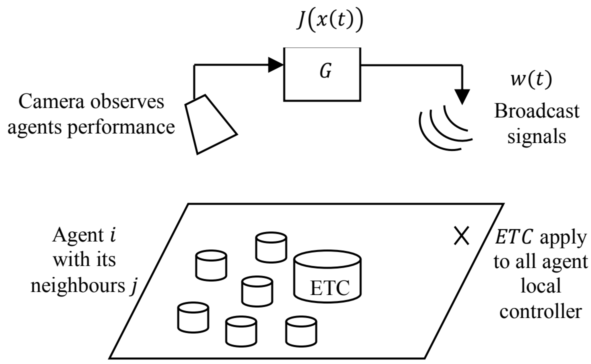

Figure 1. Multi-agent feedback system in environment with broadcast controller, G and event triggered distributed controller, ETC.

B. Graph Theory

The agent i is assumed to access with its neighbour j when it enters radius r. r represents the radius that the agent can establish a connection. The representations of agents with their neighbours are in undirected graph theory $G = (\gamma, \varepsilon)$ where γ is the vertex and ε is the edge. The agents by the list of vertex γ while the edge represents the connection between agent i with its neighbours, j represents the edges, ε or $(i,j) \in \varepsilon$. A set of all neighbours of agent is denoted by $N_i = \{(j|(i,j)) \in \varepsilon$. The representation of graph connection/topology and the number of edges ε for each vertex γ is represented in a matrix form. An adjacency matrix $A = [a_{ij}] \in R^{NXN}$ is used to describe the graph topology where $a_{ij} = 1$ if $(j,i) \in \varepsilon$ and $a_{ij} = 0$, if otherwise. The degree matrix of the system is defined as $D = diag\{d_1, d_2 \dots\dots\dots\dots d_N\}$, where $d_i = \sum_{j \in N_i} a_{ij}$.

III. PROBLEM STATEMENT

The problem of consensus which is addressed in this research study refers to a problem of collecting agents to a specific desired location $x_d \in R^n$. The agents are considered to achieve a consensus when the value of performance index measurement, $J(x(t))$ reached the minimum value or equivalent to 0 meaning that all of the agents managed to find an agreement to be in the desired target at certain time t as described as follows

$$\lim_{t \to \infty} J(x(t)) = \min_{x \in R^{nN}} (J(x)) \text{ or } 0 \quad (2)$$

It is challenging for the agents to work in the broadcast and communication environment since the agents do not know their desired location in the environment i.e. no information of world coordinate has been passed to the agents. The agents only know the achievement of their motion to the target based on the feedback information from the broadcast controller. Moreover, the agents can only calculate their distances with their neighbours when there is connection among them. The transmission of the state information will happen at time t in order to update the control input of the distributed consensus protocol as represented in (3),

$$u_i\,(\mathrm{t}) = \mathrm{K}\sum_{j\in N_i} a_{ij}\,(t)\,(\widehat{x_i}(t) - \widehat{x_j}(t)) \quad (3)$$

where u_i (t) is the control input, K is the controller gain, a_{ij} (t) is the adjacency matrix, $\widehat{x_i}(t)$ is the state of agent and $\widehat{x_j}(t)$ is the state of neighbor. In order to get the state updates, the agent has to communicate or exchange information among them continuously until it reaches consensus. In a practical situation, it is unrealistic to have a continuous signals from one agent with other agents. This proven can cause to insufficient computational resources usage, i.e. channel/bandwidth and energy when the controller keeps updating its input every time there are changes on the sensor input (as in conventional time triggered system) [26]. When it comes to situation whereby the number of agents working in the environment are increasing or the agents facing complex problems such as local minima or unforeseen area, it will make use of a higher utilization of channels (more transmission) until the agents reached a consensus. Thus, this research has come out with the idea of event triggered communication strategy to be applied into agent distributed controller to reduce the utilization of channels. The functions and an optimal parameter settings of consensus controller have been designed specifically for this research study.

IV. RESEARCH METHODS

This methodology section will explain the main design of the proposed controller which focusses on the broadcast and event triggered controllers.

A. Proposed broadcast controller with distributed event based communication control

In the feedback system as shown in Fig.2, the agent will determine its next state position, $x_i(t+1)$ based on the current state position of the agent, $x_i(t)$ and updated control input $u_i(t)$ as presented in (1). The camera will capture the position of the agent, x_i (t) to obtain the value of $J(x(t))$which represents the performances achievement of agent movement towards its desired target. The scalar value of $w(t)$ then will be sent to the local controller to determine the next control input for the local controller. Based on the local controller designed by SPSA, the agent will move randomly during even time based on the Bernoulli distribution probability ± 1value. The agent will move deterministically based on the value obtained from the gradient approximation and from agent to agent controller. The agent to agent controller will keep updating the control signal, u_i when the event triggered condition, ETC is violated. The process will then iterate continuously until it reach convergence when all agents reached its target point

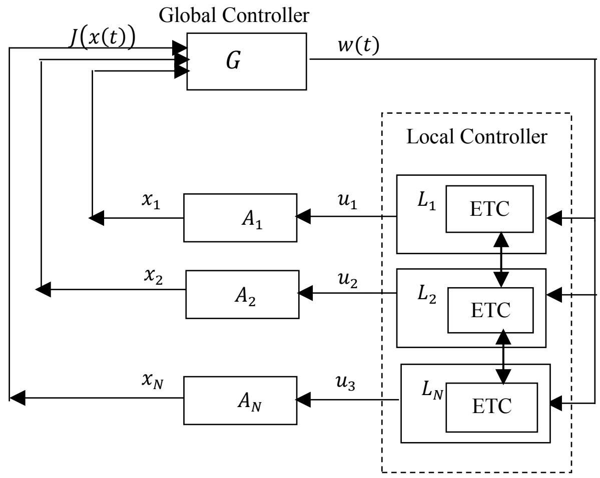

Figure 2. Proposed broadcast controller with distributed event based communication control

A global controller is represented by G play a role to observe agent performances at every t time and broadcast the signal indiscriminately to local controller as denoted in (4) where $w(t)$ is the output and $J(x(t))$is the input. $J(x(t))$is the objective function of motion coordination task to collect agents at desired location $\mathrm{x_d} \in \mathrm{R^n}$ which represents by quadratic equation (4).

$$G\colon w(t) = J(x(t)),\ \mathrm{J}(\mathrm{x}(\mathrm{t})) = \sum_{\mathrm{i}=1}^{\mathrm{N}} ||\,\mathrm{x_i}(\mathrm{t}) - \mathrm{x_d}||^2 \quad (4)$$

Meanwhile a local controller that is added into the agent $A_i$is divided into two sub controllers known as agent controller L_{i1} and agent to agent controller L_{i2}. The agent controller is designed specifically by using SPSA [27] while the agent to agent controller is develop based on distributed consensus protocol proposed by Olfati Saber [28]. The idea of having these controllers is to bring communication into broadcast controller, so that consensus can be achieved effectively in practical situation, especially when event triggered mechanism is being applied into communication between agent to agent.

i. Agent Controller, L_{i1}

Assume that the state of $\xi_i(t)$ of L_{i1} in two dimensional space, let $\xi_{i1}(t)\in R^n$, $\xi_{i2}(t)\in R$, $\xi_{i3}(t)\in R$ be the components of ;

$$\xi_\mathrm{i}(\mathrm{t}) = \begin{bmatrix}\xi_{\mathrm{i1}}\\ \xi_{\mathrm{i2}}\\ \xi_{\mathrm{i3}}\end{bmatrix} \in \mathrm{R^n} \times \mathrm{R} \times \mathrm{R} \quad (5)$$

The local controller L_{i1} is denoted by (6) where $\xi_\mathrm{i}(\mathrm{t}) \in \mathrm{R^v}$ is the state, $\mathrm{w(t)} \in \mathrm{R}$ is the input from broadcast signal,$\mathrm{u_i(t)} \in \mathrm{R^n}$ is the output and $\mathrm{a} : \mathrm{R^v} \times \mathrm{R} \rightarrow \mathrm{R^v}$ and $\mathrm{b} : \mathrm{R^v} \times \mathrm{R} \rightarrow \mathrm{R^v}$ are functions.

$$L_{i1}:\begin{cases}\xi_i(t+1)=a(\xi_i(t),w(t))\\ u_i(t)=b(\xi_i(t),w(t))\end{cases} \quad (6)$$

$$a\left(\xi_i(t),w(t)\right)=\begin{bmatrix}\Delta_i(t)\\ w(t)\\ \xi_{i3}+1\end{bmatrix} \quad (7)$$

$$b\left(\xi_i(t),z(t)\right) := \begin{cases} c\left(\xi_{i3}(t)\right)\Delta_i(t) & \text{if } \xi_{i3}(t)\in\{0,2,4\},\\ -c\left(\xi_{i3}(t)\right)\xi_{i1}(t)-d\left(\xi_{i3}(t)\right)\dfrac{z(t)-\xi_{i2}(t)}{d\left(\xi_{i3}(t)\right)}\xi_{i1}{}^{-1}(t) & \text{if } \xi_{i3}(t)\in\{1,3,5\},\end{cases} \quad (8)$$

where Δ_i (t) ∈ R is the random variable based on Bernoulli distribution, $c(\xi_i(t))$ and $d(\xi_i(t)) \in R_+$ are the gains of the controller and $\xi_{i3}(t)$ is time represent in odd or even.

Lemma 1: For the feedback system, suppose that the radius of agent i can establish connection with agent j, $r \in R_+$ and position of target, $x_d \in R^n$are given. The L_{i1} , L_{i2} , and G are given by (3), (4),(6), and (9) to satisfy (2) and (4). These equations showed that the consensus among agents formed at time t can be attained when the value of $J(x(t))$ =0 which showed that all of the agents have reached their target point.

ii. Agent to Agent Controller, L_{i2}

The controllers of L_{i2} are given by (9) where it works based on standard distributed consensus controller by Olfati [28] where K represent the controller gain and a_{ij} is the adjacency matrix of agents neighbours.

$$L_{i2}(x_j(t)-x_i(t)) = K\sum_{j\in N_i} a_{ij}(t)\,(x_j(t)-x_i(t)) \quad (9)$$

The agents that are connected with their neighbours are expected to approach each other during odd time on reaching consensus. This can formalized as follows.

Lemma 2: For agent to agent communication, suppose that L_{i2} is given by (9), event triggered protocol is given by (12) and assuming that $r \in R_+$ is given to satisfy (10)

$$\lim_{t\to\infty} x_i(t)-x_j(t)=0 \quad (10)$$

This lemma shows that the controller L_{i2} of agent $i(1,2,3,\ldots..N)$ can achieve a consensus during odd time.

iii. Event triggered communication control applied into agent to agent controller

In order to adjust the agents states in reaching the local consensus while avoiding a continuous interaction among the agent's and their neighbours, the event trigger control has been applied into this distributed agent system. The equation of distributed consensus control by Olfati (3) shows that the control input depends on the sum of agent state with its neighbours state whereby it shows that the controller will continuous update the input signal every time it receives a new state. In order to avoid a higher utilization of resources during sending the signal continuously, thus the distributed event based consensus control scheme for agent as stated in (11) is applied in the system, where K represents the controller gain, $t \in t_k^i, t_{k+1}^i$denotes the event instants time of agent i t_k^i $(k=1,2,\ldots\ldots.)$ and $t_{k'(t)}^j = argmin_{l\in N:t\ge t_l^j}$ (t-t_l^i) is the latest event time of agent j.

$$u_i(t) = -K\sum_{j\in N_i} a_{ij}\,(x_i(t_k^i)-x_j t_{k'(t)}^j) \quad (11)$$

The event triggered consensus control applied in this research is stated in (12)

$$f_i(e_i(t)) \le \Delta_i(z_i(t)) \quad (12)$$

where $f_i(.)$ and $\Delta_i(.)$ represent the error function and threshold function. The state measurement of agent i is equivalent to $e_i(t) = x_i(t_k^i)$ - x_i(t), t ∈ t_k^i, t_{k+1}^i where denotes the event instants for agent t_k^i $(k=1,2,\ldots\ldots.)$ while $z_i(t)=\sum_{j\in N_i} a_{ij}\,(x_i(t)-x_j(t))$. The threshold function is also known as a state dependent threshold where it is related to the state of agents. In distributed settings, agent i's event time instant will be determined once its triggering condition in (12) is violated. Once agent i received the triggering signal, the control signal of its input and its neighbour will be updated. This control signal will then be summed with the control signal produced from the gradient approximation calculation of SPSA to determine the value of deterministic movement during odd time as shown in Fig.3. When satisfies the event triggered condition, the control signal will not be updated since the measurement of error doesn't trigger the controller. Thus, the communication channel is free at this time and the calculation of the deterministic movement will rely more on the gradient value of agent controller.

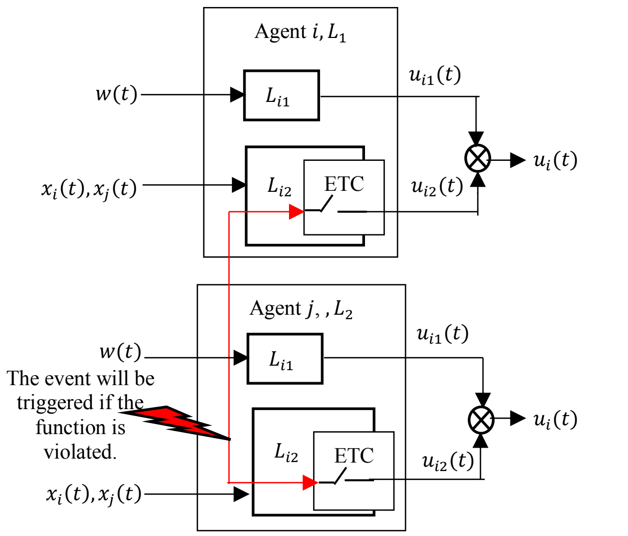

Figure 3. Event triggered control scheme for agent to agent controller.

By combining Lemma 1 and Lemma 2, the solution of consensus problem for this research is obtained.

Theorem 1: Let L_{i1} , L_{i2} , $B,\ and\ f_i(e_i(t))$ be given by (4), (6), (9), (11) and (12). If the conditions (L1), (L2) and (L3) satisfy, (2) and (10) will achieve a probability of 1. It means that consensus can be achieved by applying an appropriate design and optimal parameter settings of a local and a global controller. SPSA and event triggered mechanism are the control systems that have been focused in this research studies.

(L1) $a(t) = a(t+1)$ and $c(t) = c(t+1)$ for t {0,2,4, ….},
$\lim_{t\to\infty} a(t) = 0,\ \sum_{t=0}^{\infty} a(t) = \infty$, and $\lim_{t\to\infty} c(t) = 0$.
(L2) $\Delta_{i1}(t), \Delta_{i2}(t) \ldots\ldots \Delta_{iN}(t)$ and $(t = 1,2,3, \ldots)$ are random variables from a probability distribution which is continuous and symmetric about zero.
(L3) $0 < K < 1/N$, then (10).

Notation: Conditions (L1), (L2), and (L3) are imposed for tuning parameters for controller L_{i1} and L_{i2} . (L1) and (L2) are parameter settings of SPSA gains a and c and random distribution Δ_i. (L3) is gain K of distributed consensus protocol. These values are not restrictive in practice but they are determined based on guideline given by Spall [27] and results found from investigation [29] .

V. Simulation Results

The simulations are implemented to a ten-agent multi-agent system. Firstly, the results of motion coordination of agents in reaching consensus are illustrated. Thereafter, the results of event triggered controller in terms of utilization of communication channel is recorded.

A. Multi-agent performances with a time triggered consensus versus an event triggered consensus controller.

The optimal parameter settings of SPSA gain with an accurate objective function and distributed consensus controller gain K have been proven to achieve multi-agent consensus in a broadcast and communication environment. The optimal parameter settings for agent to reach consensus is equal to a=0.2, A=30, $\alpha = 0.6$, c=1,and $\gamma = 0.101$with gain K=0.05×10^{-3} are applied in this research. The results shows that the agents need at least an average of 746.8 iterations to converge with the average time taken of 86.52 sec in 10 times run with a time triggered consensus controller. As compared with an event triggered consensus controller, 756.3 iterations and 88.81 sec are obtained for the agents to converge in 10 times run. Thus, it can be claimed that performances of agents in terms of iteration and time didn't show a significant difference for a time triggered or event triggered consensus controller.

Fig.4(a) - Fig.4(c) illustrates the agent position x_i(t) during few iterations where the circle represents the agent and the square represents the target x_d.This results show that the proposed controllers can reach consensus at the target x_d with agent and agent-to-agent controller. Every time the iterations and the time increased, the percentage movement of agent i's to reach the target also increased which showed that the evolution of movement is positive. Finally, all agents meet at the target point at a very minimum value of $J(x(t))$ as stated in (2) and as shown in Fig 5. Fig. 5 shows the achievement of performances index of agents during time triggered and event triggered where it will reduced by the time the agents achieve consensus. Both lines in the graph are intersect since the total error that represents the state of agents with the desired target at every time are same for both triggering methods. It is also possible to produce a faster convergence by tuning an optimal parameters of SPSA [29].

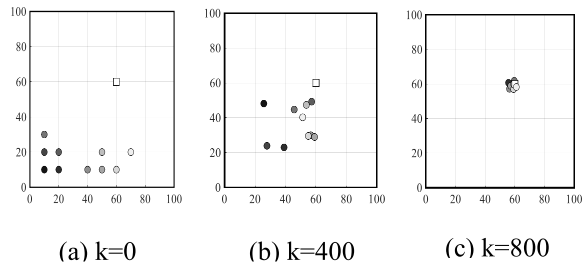

Figure 4. Evolution of iteration k of agent positions of the proposed controller ($N = 10, r = 20$ and x_d=(60,60))

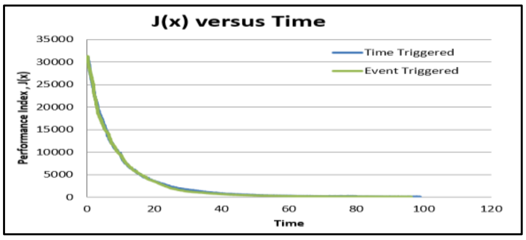

Figure 5. *J(x)* versus time.

B. Utilization of communication channel of distributed agent to agent controller with event triggered communication strategy

In order to observe the effectiveness of event triggered communication strategy in finding consensus for distributed agent-to agent controller, the event instant t_k^i of agent had been recorded as shown in Fig.6 (i.e event instant of agent i is only recorded until t=10). The results shows that event instant of ten agent i is only triggered at some times and not every time where it depends on the triggering function designed in equation (13). Based on the results, the triggering function $f(.)$ work based on the value of error $e_i(t)$. At event instant t_k^i, equation (13) holds since $e_i(t) = 0$. After $t_k^i, e_i(t)$will fluctuates until agent i is triggered when the value of error exceeds $\Delta_i(z_i(t))$. At this time the current time instant will be defined as a new event instant t_{k+1}^i. Then the new error of event instant $e_i(t_{k+1}^i)$will hold (13) until the next event instant is triggered.

Table I shows the utilization of channels for each agent i in 10 iterations. The number of channels usage is approximate to 320 channels had been used in event triggered control whereby in time triggered control about 1000 channels had been utilized. Thus, with this triggering system it can be claimed that the utilization of communication channel can be reduced where the agent has to transmit its states and receives its neighbour states only at certain time and not continuously as conventional time triggering system.

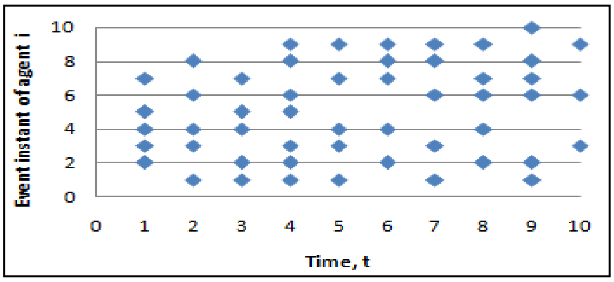

Figure 6. Event instant of agent i with event triggered distributed control.

TABLE I. NUMBER OD CHANNEL USAGE, NOC OF AGENT I IN 10 ITERATION

A_i	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}
NOC	40	30	40	40	30	30	30	30	40	10

VI. CONCLUSION

Consensus problem of multi-agent systems has been solved by combining broadcast controller with an event triggered distributed controller. Simulation results have shown the efficiency of the proposed method where the number of communication channel usage are less comparing with a conventional time triggering system. Future works include extending the proposed method by adding other problems such as stability issues, interference or dynamics in the environment can be done. Besides that, the proposed controller also can be applied in solving a heterogeneous multi-agent consensus problems.

ACKNOWLEDGMENT

The financial support by Malaysian Government and University Teknologi Malaysia for this research is gratefully acknowledged.

REFERENCES

[1] Z. Peng, S. Yang, and G. W. A. R. Y. Yu, "Adaptive Distributed Formation Control for Multiple Nonholonomic Wheeled Mobile Robots," *Neurocomputing,* pp. 1-10, 2015.

[2] T.P. Nascimento, A.P.Moreira, and A.G.S.Conceicao, "Multi Robot Nonlinear Model Predictive Formation Control: Moving Target and Target Absence," *Robotics and Autonomous Systems,* vol. 61, pp. 1502-1515, 2013.

[3] B. Hou, F.Sun , and H. L. Y. C. G. Liu, "Observer Based Cluster Consensus Control of High Order Multi Agent Systems," *Neurocomputing,* vol. 168, pp. 979-982, 2015.

[4] K.Das and D.Ghose, "Broadcast Control Mechanism for Positional Consensus in Multiagent System," *IEEE Transactions on Control Systems Technology,* pp. 1-20, 2015.

[5] Q. Ma and G.Miao, "Output Consensus for Heterogeneous Multi Agent Systems With Linear Dynamics," *Applied Mathematics and Computation,* vol. 271, pp. 548-555, 2015.

[6] A. Wang, "Event Based Consensus Control for Single Integrator Networks With Communication Time Delay," *Neurocomputing,* pp. 1-17, 2015.

[7] H.Haghshenas, M.A.Badamchizadeh, and M.Baradarannia, "Containment Control of Heterogeneous Linear Multi Agent Systems," *Automatica,* vol. 54, pp. 210-216, 2015.

[8] L. Bo, C. Z.Qiang, and L. Z. X. Z. C.Yan.Z.Qing, "Containment Control of Multi Agent Systems With Fixed Time Delays in Fixed Directed Networks," *Neurocomputing,* pp. 1-17, 2015.

[9] L.Rong, H. Shen, and J. L. J. Li, "Distributed Reference Model Based Containment Control of Second-Order Multi Agent Systems," *Neurocomputing,* vol. 168, pp. 254-259, 2015.

[10] Z.Liu, Q. Jin, and Z.Chen, "Distributed Containment Control for Bounded Unknown Second Order Nonlinear Multi Agent Systems With Dynamic Leaders," *Neurocomputing,* vol. 168, pp. 1138-1143, 2015.

[11] J.D.Lope, D.Maravall, and Y.Quinonez, "Self-Organizing Techniques to Improve the Decentralized Multi Task Distribution in Multi Robot Systems," *Neurocomputing,* vol. 163, pp. 47-55, 2015.

[12] L.Rosa, M.Cognetti, and A. N. P. A. G. Oriolo, "Multi Task Cooperative Control in a Heterogeneous Ground Air Robot Team," *3rd IFAC Workshop on Multivehicle Systems,* vol. 48, pp. 53-58, 2015.

[13] S. Azuma, R.Yoshimura, and T.Sugie, "Multi-Agent Consensus Under a Communication Broadcast Mixed Environment," *International Journal of Control,* vol. 87, pp. 1103-1116, 2014.

[14] T.H Lee, J.H .Park, and D. H. Ji.H.Y.Jung, "Leader Following Consensus Problem of Heterogeneous Multi-Agent Systems With Nonlinear Dynamics Using Fuzzy Disturbance Observer," *Complexity,* vol. 19, pp. 20-31, 2014.

[15] G.S. Seyboth, D. V.Dimarogonas, and K. H. Johansson, "Event Based Broadcasting for Multi Agent Average Consensus," *Automatica,* vol. 49, pp. 245-252, 2013.

[16] W. Zhu, Z.P.Jiang, and G. Feng, "Event-based Consensus of Multi-Agent Systems With General Linear Models," *Automatica,* vol. 50, pp. 552-558, 2014.

[17] K. Das and D. Ghose, "Positional Consensus in Multi Agent Systems Using a Broadcast Control Mechanism," *2009 American Control Conference* pp. 5731-5736, 10-12 June 2009 2009.

[18] P. Wieland, R. Sepulchre, and F. Allgower, "An Internal Model Principle is Necessary and Sufficient for Linear Output Synchronization," *Automatica,* vol. 47, pp. 1068-1074, 2011.

[19] Z. Li, Z.Duan, and F.L.Lewis, "Distributed Robust Consensus Control of Multi Agent Systems With Heterogeneous Matching Uncertainties," *Automatica,* vol. 50, pp. 883-889, 2014.

[20] X. Wang, H. Ji, and C. Wang, "Distributed Output Regulation of Leader Follower Multi Agents Systems," *International Journal of Robust and Nonlinear Control,* pp. 524-538, 2013.

[21] Y. Su and J. Huang, "Cooperative Output Regulation of Linear Multi-Agent Systems," *IEEE Transactions on Automatic Control,* vol. 57, pp. 1062-1066, 2012.

[22] C. Nowzari and J.Cortes, "Zeno-Free, Distributed Event Triggered Communication and Control for Multi Agent Average Consensus," *2014 American Control Conference (ACC),* pp. 4-6 June 2014, 2014.

[23] R. Vatankhah, S. Etemadi, and A.Alasty.G.Vossoughi, "Adaptive Critic Based Neuro Fuzzy Controller in Multi Agents: Distributed Behavioral Control and Path Tracking," *Neurocomputing,* vol. 88, pp. 24-35, 2012.

[24] R.Socas, S.Dormido, R.Dormido, and E.Fabregas, "Event-Based Control Strategy for Mobile Robots in Wireless Environment," *Journal of Sensors,* pp. 30076-30092, 2015.

[25] L.Zhang, Z.Li, J. Yan, and X.Guan, "Event-Triggered Multitarget Formation Control for Multiagent Sytems," *Hindawi:Mathematical Problems in Engineering,* pp. 1-8, 2017.

[26] L.Ding, Q.L.Han, X.Ge, and X.-M. Zhang, "An Overview of Recent Advances in Event-Triggered Consensus of Multi-agent Systems," *IEEE Transactions on Cybernetics,* pp. 1-7, 2017.

[27] J. C. Spall. (1998) An Overview of the Simulteneous Pertubation Method for Efficient Optimization. *John Hopkins Application Technical Digest*.

[28] R.O. Saber, J. A. Fax, and R. M.Murray, "Consensus and Coooperation in Networked Multi Agent Systems," *Proceedings of the IEEE,* vol. 95, pp. 215-233, January 2007.

[29] N.Sariff and Z.Hilmi, "Simultaneous Perturbation Stochastic Algorithm Parameters Effect Towards Multi Agent Robot Broadcast Controller," *2017 IEEE 7th International Conference on Underwater System Technology: Theory and Applications,* pp. 1-6, 2017.