Capstone Engineering Project EGH400-1 / EGH408 / BEB801-1
Semester Two 2020

# Topic Investigation via the Engineering Literature

**Submit:** Electronically, via Blackboard Assessment Upload
**Due date:** 16-August

**Name:** Liam Dale

**Student No.:** n9741283

**Draft Research Topic Title:** Event-triggered consensus control approach for guaranteed finite time convergence

**Project Supervisor:** Dr. Aaron McFayden

**Your BEng Degree Major:** Electrical Engineering

**Assessment Tasks**

- Draw a concept map of your research topic;
- Translate those key concepts into a search statement;
- Search for relevant engineering literature;
- Identify authoritative, reputable and reliable information sources on your research topic;
- Submit a summary analysis of three key references;
- Identity and categorize trends found in the literature;
- Explain what impact literature findings have had on the design of your project;
- Locate published authorities (acknowledged experts) in your field of research;
- Compile a reference list of the most useful literature on your topic.

**This assessment item will be marked by your project supervisor.**

On completion of this assessment you should have formed an information research strategy that will allow you to discover evidence based scholarly, trade and professional literature that will underpin your research project.

Guidance is available from the QUT Library web site, including relevant library subject guides.

Advice on literature discovery is available from the HiQ service point (V block level 3), Online Help (Chat or email) or consultation (by appointment) with an engineering librarian.

## 1. Concept Map

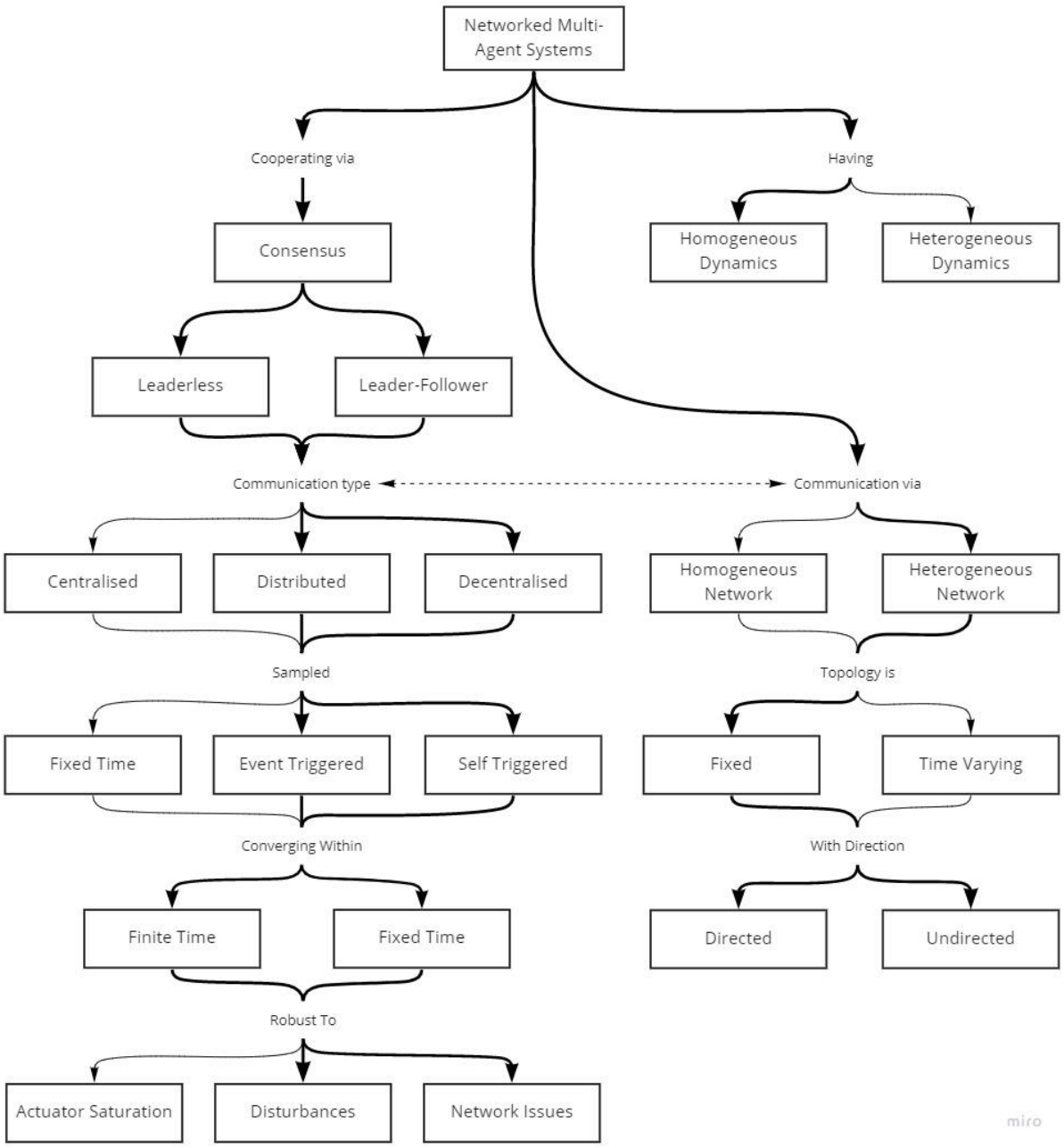
Draw a concept map that defines your topic

Describe the objective and scope of your research topic.

**Objective:** To investigate event triggered consensus control schemes which guarantees finite time convergence

**Scope:** Multi-agent unmanned aerial systems with known dynamics. The intent is operation of many drones within a dense urban environment.

Concept maps are diagrams that show relationships among concepts. They are graphical tools that organize knowledge. Refer to the Blackboard site for guidance on how to draw a concept map. Background reading will assist in this process.




*Take the terms and phrases from your concept map to develop and refine a search strategy.*

## 2. Developing a Search Statement
Planning a search strategy

Separately identify the **key concepts** you wish to search for:

| 1st Concept | | 2nd Concept | | 3rd Concept | | 4th Concept |
|---|---|---|---|---|---|---|
| Multi Agent | AND | Consensus Control | AND | Event-Triggered | AND | Finite-Time |

Now list any synonyms (words with the same or similar meaning) that may also retrieve relevant information. List here any spelling variations e.g., colour / color ; tire / tyre ; harbour / harbor.

| Synonyms | | Synonyms | | Synonyms | | Synonyms |
|---|---|---|---|---|---|---|
| Multiple Robot<br>OR<br>Multiple Vehicle | AND | Cooperative Control | AND | Event-Triggering<br>OR<br>Event-Sampling<br>OR<br>Event-Sampled<br>OR<br>Event-Based<br>OR<br>Self-Triggered<br>OR<br>Self-Triggering | AND | Fixed-Time |

OR

OR

As an alternative to the Boolean **OR** search operator you can (where appropriate) opt to truncate a search keyword. Apply the keyword truncation symbol (usually an asterisk ***** ) to the stem of a word in order to simultaneously retrieve the plural form, plus synonymous variant right-hand grammatical endings of your search keyword.
*e.g., spectr* will retrieve spectra, spectral, spectrometry, spectroscopy, spectrum, spectrums.*
List those of your search keywords than can be usefully truncated in the box below:

| multi* trigger* sampl* |
|---|

Structure your search statement using **Boolean** search logic operators **(AND, OR, NOT).**
Use parentheses ( ) so that you can order a **keyword** search. Enclose a literal text string in inverted commas to force an exact key **phrase search**. For example:
("artificial intelligence" OR "fuzzy logic") AND (power AND (distribution OR transmission))

(Multi* AND (Agent OR Robot OR Vehicle)) AND ((consensus OR cooperative) AND control) AND ((Event AND (Trigg* OR Sampl* OR Based)) OR "self trigger*") AND ("Finite-Time" OR "Fixed-Time")

**QUT Library Seach:**
7,995 results with keyword search
763 results with keyword search filtered by 2015-2020, online and peer reviewed

## 3. Searching for Engineering Literature
## Explore relevant engineering literature databases.

Name the most useful engineering literature database searched: Identify this database (and if applicable, its delivery platform). For example, Inspec (Engineering Village); Transportation Research Information Database (TRID); ASCE Research Library; Compendex (on Engineering Village).

**Database Name:**
IEEE Xplore digital library

**Comment on the scope of your chosen database and why it proved to be of high value to your literature search:**
Being powered by such a large and venerable technical organisation the IEEE Xplore digital library has high regard. The online platform provides full-text, relevant and peer-reviewed resources.

There is a good depth and range including books, conferences, courses, journals and magazines, and standards which are related to IEEE. This old database will chronologically cover the relatively new research topic.

The Boolean search retrieves 12 journals, 11 conference and 9 early access articles for a total of 32 results spanning back to 2013. Of these 24 are published as recently as 2018.

There are search aid features useful for finding topic-related resources. A more generalised version of the Boolean search can be performed to get a greater depth of results, filterable by keywords for an analogous result. Other filters such as year, affiliation, publication title and publisher may be used to discern up to date and trustworthy resources.

Functionalities to filter by author and publication title provide a good starting point to highlight prolific authorities on a topic.

## 4. Identify Relevant and Authoritative Information Sources

List key information sources applicable and relevant to your research topic.
The engineering capstone project guide will assist.
Attempt to include at least one in each of the following categories:

**a. Peer Reviewed Journal Title**

- IEEE Transactions on Automatic Control
- IET Control Theory & Applications
- IEEE Access
- IEEE Transactions on Control of Network Systems
- IEEE Control Systems Letters
- IEEE Transactions on Control Systems Technology

**b. Conference Proceeding**

- 20xx Chinese Control Conference
- 20xx IEEE Conference on Decision and Control

- 20xx European Control Conference
- 20xx American Control Conference

**c. Engineering Texts**

- Distributed Consensus in Multi-Vehicle Control Theory
- Fixed-Time Cooperative Control of Multi-Agent Systems

**d. Handbooks / Encyclopaedia**

- Encyclopedia of Systems and Control

**e. Standard (or regulation)** – finding Standards guide will assist.

- 19/30390138 DC {BS EN 4709-001} Aerospace series. Unmanned Aircraft Systems. Product requirements and verification for the Open category
- BS ISO 21384-3:2019 Unmanned aircraft systems. Operational procedures

**f. Patent** – the finding Patents guide will assist.

- CN109379125B Multi-agent formation control method and system

## 5. Evaluate and Analyse Three (3) Key References

From your search results select three key references. For each reference (typically these will be journal articles or conference papers or book chapters) provide an evaluation and analysis using the template below. Consider attributes such as currency, relevance, accuracy, authority and purpose.

| **Reference # 1 – IEEE (IEEE citation style)** |
|---|
| **Citation:**<br>P. Tabuada, "Event-Triggered Real-Time Scheduling of Stabilizing Control Tasks," in IEEE Transactions on Automatic Control, vol. 52, no. 9, pp. 1680-1685, Sept. 2007, doi: 10.1109/TAC.2007.904277. |
| ***How does this paper relate to my topic?***<br>This is an older paper pioneering investigating an event scheduler, regarded as a feedback controller. This forms the basis for event triggered control. |
| ***What key findings are reported?***<br>-Event-triggered scheduling algorithm that executes control task when error becomes large compared with the state norm.<br>-Semi-global asymptotic stability is guaranteed.<br>-Minimal time to exclude Zeno and allow for software execution. |
| ***How does this paper relate to other work in the field?***<br>This paper provides an alternative to fixed time sampling for better resource utilisation. Being old it doesn't have as much functionality as contemporaries. It is not placed within the context of multi agent systems, or consensus control and doesn't guarantee finite time convergence. |
| ***Interpret important figures / tables / illustrations (cite the page number).*** |

Fig 1. (pg. 1693) illustrates the state error maximum being hit and triggering a stabilising control task.

Table 1. (pg. 1694) shows inter-execution times for different error margins. Discussion is presented on the simulated/estimated ratio.

***List other references to investigate further (a good paper can often lead to another).***

L. Palopoli, C. Pinello, A. S. Vincentelli, L. Elghaoui, and A. Bicchi, C. Tomlin and M. R. Greenstreet, Eds., "Synthesis of robust control systems under resource constraints," in Proc. Hybrid Systems: Computation and Control, 2002, pp. 337–35

J. Yook, D. Tilbury, and N. Soparkar, "Trading computation for bandwidth: Reducing communication in distributed control systems using state estimators,

***General notes / observations on this paper's attributes.***

The scheduling implemented is simple, and so could be used as a toy problem to get introduced to the space before working on more complex approaches. This will help with setting up a simulation space and familiarisation taking math to code. Numerical examples for validation.

*IEEE Link (Document 4303247) has 1849 text citations, 1 patent citation, 12369 full text views. Strong community engagement and IEEE name give authority.*

**Reference # 2 – IEEE (IEEE citation style)**

**Citation:**

L. Ding, Q. Han, X. Ge and X. Zhang, "An Overview of Recent Advances in Event-Triggered Consensus of Multiagent Systems," in IEEE Transactions on Cybernetics, vol. 48, no. 4, pp. 1110-1123, April 2018, doi: 10.1109/TCYB.2017.2771560.

***How does this paper relate to my topic?***

This paper provides a summary on the literature trends of event triggered control. Being published in early 2018 it is recent and fairly comprehensive, but missing the most cutting edge developments. It is a good starting place to stem the research review and find additional sources. High level overview given of frameworks and schemes which explain mechanisms and purpose. Limitations and challenges presented.

***What key findings are reported?***

-Practically, it is infeasible to have continuous communications across agents and neighbours; the sampled data approach is one way to overcome this.
-There are many conflicting sampled data approaches, each with trade-offs between complexity, stability and resource utilisation.
-Avoid zero inter-event times to preclude Zeno behaviour. This becomes harder with more agents, as the condition is more frequently triggered.
-In systems with many agents a centralised approach is impractical, so multi agent consensus typically employs distributed or decentralised methods

***How does this paper relate to other work in the field?***
This paper is a summary of the current ETC technologies. Findings are methodically linked to sources. Mentions of self-triggering scheme links to plant dynamics. Mentions team-triggered coordination but has no discussion. It does not present a new pioneering approach.

***Interpret important figures / tables / illustrations (cite the page number).***
Fig 1 (pg. 1112). Shows how the mechanism operation within flow chart with emphasis on overall network. High level detail.

Table 1 (pg. 1117). highlights the advantages of different communication schemes. Links these back to related literature.

***List other references to investigate further (a good paper can often lead to another).***
C. Nowzari and J. Cortés, "Team-triggered coordination for real-time control of networked cyber-physical systems," IEEE Trans. Autom. Control, vol. 61, no. 1, pp. 34–47, Jan. 2016.

X. Wang and M. D. Lemmon, "Self-triggered feedback control systems with finite-gain L2 stability," IEEE Trans. Autom. Control, vol. 54, no. 3, pp. 452–467, Mar. 2009

Q. Lu, Q.-L. Han, B. Zhang, D. Liu, and S. Liu, "Cooperative control of mobile sensor networks for environmental monitoring: An event triggered finite-time control scheme," IEEE Trans. Cybern., vol. 47, no. 12, pp. 4134–4147, Dec. 2017.

***General notes / observations on this paper's attributes.***
Could be used to find references which progressively build upon the reference #1 toy problem. E.g. D. V. Dimarogonas, E. Frazzoli, and K. H. Johansson, "Distributed event-triggered control for multi-agent systems," IEEE Trans. Autom. Control, vol. 57, no. 5, pp. 1291–1297, May 2012.

*IEEE Link (Document 8115253) has 113 citations, and 5950 paper views. Strong community engagement and IEEE name give authority. Supplementing this are references to other overviews within the document.*

**Reference # 3 – IEEE (IEEE citation style)**

**Citation:**
R. R. Nair, L. Behera and S. Kumar, "Event-Triggered Finite-Time Integral Sliding Mode Controller for Consensus-Based Formation of Multirobot Systems With Disturbances," in IEEE Transactions on Control Systems Technology, vol. 27, no. 1, pp. 39-47, Jan. 2019, doi: 10.1109/TCST.2017.2757448.

***How does this paper relate to my topic?***
After seeing a pioneering paper and an overview in references #1 and #2, this resource introduces a contemporary and novel approach to event-triggered finite-time consensus formation which is robust to bounded disturbances.

***What key findings are reported?***
-Sliding mode control algorithm to achieve consensus despite of external bounded disturbances
-Event triggered control, where there is stable finite time convergence
-Bounded lower interexecution time to exclude Zeno behaviour

-Convergence has been expedited by using fast reaching law

***How does this paper relate to other work in the field?***
Previous works don't combine all the listed findings, whereas this is a combination of all those mechanisms. The findings are restricted to leader-follower consensus with a directed graph topology.

***Interpret important figures / tables / illustrations (cite the page number).***
Fig 1. (pg 41) shows the block schematic of the event-triggering scheme. This is a novel approach, which is more developed than seen in reference #2. Additionally includes a leader (chief) state into the diagram. Sliding mode planned path is summed with leader and follower states to inform the event triggering condition.

Figs 14-16. (pg 45) display the experimental results of position and velocity, the error and triggering times of agents.

***List other references to investigate further (a good paper can often lead to another).***
Y. Zhu, X. Guan, X. Luo, and S. Li, "Finite-time consensus of multiagent system via nonlinear event-triggered control strategy," IET Control Theory Appl., vol. 9, no. 17, pp. 2548–2552, Nov. 2015.

Y. Zhu, X. Guan, X. Luo, and S. Li, "Finite-time consensus of multiagent system via nonlinear event-triggered control strategy," IET Control Theory Appl., vol. 9, no. 17, pp. 2548–2552, Nov. 2015.

A. K. Behera and B. Bandyopadhyay, "Self-triggering-based sliding mode control for linear systems," IET Control Theory Appl., vol. 9, no. 17, pp. 2541–2547, Nov. 2015.

***General notes / observations on this paper's attributes.***
This approach is not necessarily the ideal one for this research task. It is selected as a key reference due to its popularity and how recent it is. It also covers a range of relevant topics which should be better understood.

It is a very technical paper, with heavy maths. To ease into the understanding there is a trail of less complex references which don't tackle so many concepts at once. As an example, the results are directly linked to the thirteenth reference which is a less robust implementation of fixed time event triggered consensus control.

IEEE Link (Document 8065034) has 8 citations, and 1986 text views. *Strong community engagement over brief timeframe and IEEE name give authority.*

## 6. Literature Synthesis and Impact on Your Project Design

**Categorize major findings (issues, trends or themes) apparent in this your preliminary investigation of the literature.**

Consensus control is rapidly evolving area of research, due to the diverse applications mobile robots can have. To actualise this topic there is a trending research stream focussing on the challenges faced with real world systems.

1. In practical implementations it is unrealistic to have continuous signals from agents and neighbours, as this places burden on resource utilisation. Sampled data approaches overcome this limitation at the expense of more complicated control protocol design.
    a. There is debate regarding the best sampled data approach; each has a trade-off between complexity, stability and resource utilisation
    b. There are restricted network topologies where protocols are stable. It is an added challenge designing for all forms.
    c. Systems will be subject to stochastic disturbances and uncertainties such as packet loss or time so they must be robust.
2. Convergence rate is a performance metric for consensus control. Finite time control methodology is being looked at to improve convergence rate and robustness over asymptotically stable control.
    a. Settling time is dependent on initial states, so within this fixed time is being looked at.

**Describe and explain what impact these findings might have on the direction, focus or scope of your research project.**

With these findings the scope of the research project can be further refined. Existing research into event triggered control with guaranteed finite time convergence can be improved. This may take the form of added robustness, expedited convergence or topology expansion to an existing implementation.

## 7. Published Authorities

Researchers who have published on your topic

Name up to three (3) published authors who are clearly expert on your topic. State why you believe they are expert. You can usually judge this from the extent and quality of material they have published. If it is given, list their latest institutional affiliation (i.e., where they work). Your expert may have a professional web page that lists their recent publications, their experience and engagement with the research question / problem.

### 1. Wei Rin

This author has been extensively cited, and has been writing on networked control for a decades. Has several texts more specific to event triggered, finite time consensus.

Currently a Professor with the Department of Electrical and Computer Engineering, University of California, Riverside. IEEE fellow. Affiliation Page: https://intra.ece.ucr.edu/~ren/.

Expertise:

- 40,731 Google Scholar citations across 342 works. Listed works span 1990 to 2020.

- Relevant research interests include multi-agent systems, cooperative control, distributed control, networked control systems, autonomous systems
- Ph.D. degree in Electrical Engineering from Brigham Young University, Provo, UT 2004
- Written books D*istributed Coordination of Multi-agent Networks* and *Distributed Consensus in Multi-vehicle Cooperative Control*
- Recipient of the Antonio Ruberti Young Researcher Prize in 2017 and the National Science Foundation CAREER Award in 2008.
- Associate Editor for Automatica and Systems and Control Letters

Google Scholar: https://scholar.google.com/citations?user=c4lfArMAAAAJ&hl=en

**2. Wenwu Yu**

This author is extremely active with current affiliations and publishing which is important when noting how quickly the subject area is evolving. Relevant areas of research which are more niche than author (1), but still related.

Currently affiliations:

- Deputy Associate Director of Jiangsu Provincial Key Laboratory of Networked Collective Intelligence
- Associate Director in the Research Centre for Complex Systems and Network Sciences
- Associate Dean in the School of Mathematics, and a Full Professor with the Young Endowed Chair Honour in Southeast University, China.
- IEEE fellow

Affiliation page: https://math.seu.edu.cn/yww_en/list.htm

Expertise:

- 17,036 Google Scholar citations across 258 works. Listed works span 2005 to 2019.
- Relevant research interests include multi-agent systems, complex networks and systems, disturbance control, distributed optimization
- PhD Degree, Department of Electronic Engineering, City University of Hong Kong 2010
- Master Degree, Department of Mathematics, Southeast University, Nanjing, China 2007
- Listed Thomson Reuters Highly Cited Researchers in Engineering in 2014 – 2019
- Server as an editorial board member of several flag journals:
    - IEEE Transactions on Industrial Informatics
    - IEEE Transactions on Systems, Man, and Cybernetics: Systems
    - IEEE Transactions on Circuits and Systems II
    - Science China Information Sciences, Science China Technological Sciences

Google Scholar: https://scholar.google.com/citations?user=I7XxngUAAAAJ&hl=en

3. **Gang Feng**

This author has been lecturing and writing on multi-agent control for decades. The most cited IEEE author for event triggered consensus.

Currently affiliated professor with City University of Hong Kong Department of Biomedical Engineering Kowloon, Hong Kong. IEEE Fellow. Affiliation Page: https://www.cityu.edu.hk/bme/megfeng/.

Expertise:

- 330 Listed work on dblp spanning 1994-2020.
- Relevant research interests Intelligent systems and control, hybrid systems and control, networked control systems, multi-agent systems and control

- Ph.D. degree in electrical engineering from the University of Melbourne, Australia
- The IEEE Transaction on Fuzzy Systems Outstanding Paper Award
- Server as an editorial board member of several flag journals:
  - Associate Editor, *Journal of Systems Science and Complexity*
  - Associate Editor, *IEEE Trans. Automatic Control*
  - Associate Editor, *IEEE Trans. on Fuzzy Systems*
  - Associate Editor, *IEEE Trans. Systems, Man, and Cybernetics*
  - Associate Editor, *Journal of Control Theory and Applications*
  - Associate Editor, *Conference Editorial Board of CSS of IEEE*

IEEE Author Page: https://ieeexplore-ieee-org.ezp01.library.qut.edu.au/author/37085356799

## 8. Reference List

Cite (using QUT cite | write's APA style or an alternative citation style agreed with your supervisor such as the IEEE citation style at least eight (8) of the most relevant and useful references you have read on your project topic. This will likely form the basis of your project report reference list. This list should be in alphabetical order, by first named author's surname.

**Referencing style used:**
IEEE

**References:**


C. Du, X. Liu, W. Ren, P. Lu and H. Liu, "Finite-Time Consensus for Linear Multiagent Systems via Event-Triggered Strategy Without Continuous Communication," in IEEE Transactions on Control of Network Systems, vol. 7, no. 1, pp. 19-29, March 2020, doi: 10.1109/TCNS.2019.2914409.

H. Zhang, G. Feng, H. Yan and Q. Chen, "Observer-Based Output Feedback Event-Triggered Control for Consensus of Multi-Agent Systems," in IEEE Transactions on Industrial Electronics, vol. 61, no. 9, pp. 4885-4894, Sept. 2014, doi: 10.1109/TIE.2013.2290757.

J. Liu, Y. Zhang, Y. Yu and C. Sun, "Fixed-Time Event-Triggered Consensus for Nonlinear Multiagent Systems Without Continuous Communications," in IEEE Transactions on Systems, Man, and Cybernetics: Systems, vol. 49, no. 11, pp. 2221-2229, Nov. 2019, doi: 10.1109/TSMC.2018.2876334.

L. Ma, Z. Wang and H. Lam, "Event-Triggered Mean-Square Consensus Control for Time-Varying Stochastic Multi-Agent System With Sensor Saturations," in IEEE Transactions on Automatic Control, vol. 62, no. 7, pp. 3524-3531, July 2017, doi: 10.1109/TAC.2016.2614486.

N. Mu, X. Liao and T. Huang, "Event-Based Consensus Control for a Linear Directed Multiagent System With Time Delay," in IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 62, no. 3, pp. 281-285, March 2015, doi: 10.1109/TCSII.2014.2368991.

P. Wang, G. Wen, X. Yu, W. Yu and Y. Lv, "Consensus Disturbance Rejection for Linear Multiagent Systems With Directed Switching Communication Topologies," in IEEE Transactions on Control of Network Systems, vol. 7, no. 1, pp. 254-265, March 2020, doi: 10.1109/TCNS.2019.2903005.

R. Olfati-Saber, J. A. Fax and R. M. Murray, "Consensus and Cooperation in Networked Multi-Agent Systems," in Proceedings of the IEEE, vol. 95, no. 1, pp. 215-233, Jan. 2007, doi: 10.1109/JPROC.2006.887293.

T. Cheng, Z. Kan, J. R. Klotz, J. M. Shea and W. E. Dixon, "Event-Triggered Control of Multiagent Systems for Fixed and Time-Varying Network Topologies," in IEEE Transactions on Automatic Control, vol. 62, no. 10, pp. 5365-5371, Oct. 2017, doi: 10.1109/TAC.2017.2693824.

W. Hu, L. Liu and G. Feng, "Consensus of Linear Multi-Agent Systems by Distributed Event-Triggered Strategy," in IEEE Transactions on Cybernetics, vol. 46, no. 1, pp. 148-157, Jan. 2016, doi: 10.1109/TCYB.2015.2398892.

Y. Zhu, X. Guan, X. Luo and S. Li, "Finite-time consensus of multi-agent system via nonlinear event-triggered control strategy," in IET Control Theory & Applications, vol. 9, no. 17, pp. 2548-2552, 19 11 2015, doi: 10.1049/iet-cta.2014.0533.