International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2018): 7.426

Networked Control Systems - A Brief Survey

Ravshan Islomov, Shuang Wan, Ayzada Temirkhanova

School of Automation/Zhejiang University of Science and Technology, Hangzhou-310023, China

Abstract: ***The area of Networked Control Systems (NCS) is attracting more and more attention in recent years. In this paper, it compares and shows differences with traditional control systems and modern NCS. The various components of NCS are connected through communication networks with benefits such as maintenance and low cost. However, the introduction of communication networks into control systems will bring several challenging issues due to limited communication capacity, such as packet dropouts, network-induced delays, quantization, data rate and media access constraints. Due to these network-induced issues, the performance of NCS will be much degraded and control systems can even become unstable. Therefore, it is of both theoretical and practical significance to develop novel approaches to analysis and synthesis of NCS in order to reduce the adverse effects of these network-induced issues.***

General terms: Networked Control Systems (NCS), closed loop, state feedback.

Keywords: Networked Control systems (NCS)

1. Literaure Review

Brief history of Networked Control Systems

When a traditional feedback control system is closed via a communication channel (such as a network), which may be shared with other nodes outside the control systems, then the control system is classified as a network control system (NCS).). All definitions found in literature for an NCS have one key feature in common. The root of control systems can be traced back to 1868 when dynamics analysis of the centrifugal governor was conducted by the famous physicist J. C. Maxwell [1]. The most significant achievement in conventional control systems occurred when the Wright brothers made their first successful test flight in 1903 [2]. The next significant achievement was the fly-by wire flight control system that was designed to eliminate the complexity, fragility, and weight of the mechanical circuit of hydro mechanical flight control systems using an electrical circuit. The simplest and earliest configuration of analog fly-by wire flight control systems was first fitted to the Avro Vulcan in the 1950s. This can be called as the first form of analog NCSs. Digital computers became powerful tools in control system design, and microprocessors added a new dimension to the capability of control systems.

A communication network is the backbone of the NCS. Reliability, security, ease of use, and availability are the main issues while choosing the communication type. The ARPANET developed by the Advanced Research Projects Agency of the U.S. Department of Defense in 1969 was the world's first operational packet switching network and the predecessor of the Internet. Later came field bus (around 1988)—which is an industrial network system for real-time distributed control. Field bus is a generic term which describes a modern industrial digital communication network intended to replace the existing 4–20-mA analog signal standard. This network is a digital bidirectional multidrug serial bus used to link isolated field devices particularly in the automated manufacturing environment. A process field bus is a standard for field bus communication in automation technology and was first promoted in 1989 by the German Federal Ministry of Education and Research (BMBF) [3]. Controller–area network (CAN) is one of the other field bus standards—which is a serial asynchronous MultiMate communication protocol designed for applications needing high-level data integrity and data rates of up to 1 Mb/s. CAN was introduced in 1980s by Robert Bosch GmbH for connecting electronic control units (ECUs) for automotive applications (vehicle bus) [4], following the flyby- wire technology in flight control. CAN-based DCSs have two main restrictions. They are the size of the distributed area and the need for communication with the following: 1) with other local area networks and 2) with remote CAN segments. Thus, there is a wide variety of competing field bus standards, and therefore, many times interoperability becomes an issue. Some of the proposed solutions for this are an extensible device description based on XML [6] and integrated field bus network architecture [5]. Another communication network used in NCSs—Ethernet—has evolved into the most widely implemented physical and link layer protocol today, mainly because of the low cost of the network components and their backward compatibility with the existing Ethernet infrastructure. Now, we have fast Ethernet (10–100 Mb/s) and gigabit Ethernet (1000 Mb/s) [7]. Recently, switched Ethernet became a very promising alternative for real-time industrial applications due to the elimination of uncertainties in the traditional Ethernet. The motivation behind wireless NCS (WNCS) is due to fully mobile operations, flexible installations, and rapid deployments for many compelling applications like automated highway systems, factories, etc. Rapid progress in sensing hardware, communications, and low-power computing has resulted in a profusion of commercially available wireless sensor nodes [8]. Wireless sensor node research in itself is a vast and big research topic.

In the 19th century which followed J.C. Maxwell's 1868 publications on steam engine regulation using centrifugal governors dealt in an increasingly rigorous way with design principles of specific feedback systems, the very general methods of design and analysis that followed Nyquist's 1932 paper were revolutionary insofar as they provided principles that could be applied to virtually any feedback system. After 1950, there was growing interest in the use of digital computers as instrumentation for feedback control. In passing from the continuous-time / continuous-state models used in classical feedback designs to the discrete-time / quantized – state design of digital control, design choices involving sampling rates, effects of finite word length and compensation for phase lags needed to be made. After half a century of research and implementation experience the foundations of digital control theory are now firmly established and can be found in many textbooks. What is different today is that technology can put low-cost processing power at remote locations via microprocessors and that information can be transmitted reliably via shared digital networks or even wireless connections. These technologies – driven changes are fueled by the high costs of wiring and the difficulty in introducing additional components into the systems as the needs change. Although networked control system technologies are now fairly mature in a variety of industrial applications, recent trend toward integrating devices through wireless rather than wired communication channels has highlighted important potential application advantages as well as several challenging problems for current research. These challenges involve the optimization of performance in the face of constraints on communication bandwidth, congestion and contention for communication resources, delay, jitter, noise, fading and the management of signal transmission power [9].

2. Introduction

The Networked Control Systems have received great attention recently. They are feedback systems in which the plant and controller communicate through a shared network. Such systems have wide applications, including mobile sensor networks, multi-agent systems and automated highway systems and etc. Many papers on this topic have been published in technical journals and conferences [14] and there have been many theoretical developments in the area of stability analysis for networked control systems [15]. However, computational tools which implement the theory are lacking. So this field is not finished yet and there are still many discoveries. Despite lots of successes of Networked control systems are still very wide studying field in research area [16]. Because its opportunities we can improve our achievements in engineering fields. To sum up, Networked Control Systems are worthy of research area even present time.

A Networked Control System (NCS) is a control system where the control loops are closed through a communication network. The defining feature of an NCS is that control and feedback signals are exchanged among the system's components in the form of information packages through a network.

Communications and control have traditionally been areas with little common ground. Communications theory is mainly concerned with the reliable transmission of information from one point to another, and is relatively indifferent to the specific purpose of the transmitted information and whether it is eventually feedback to the source [13]. Control theory, in constraint is concerned mainly with using information in a feedback loop to achieve some performance objective, and usually assumes that limitations in the communication links do not affect performance significantly [12].

In technological terms, networked control systems are comprised of the system to be controlled and of actuators, sensors, and controllers whose operation is coordinated through some form of communication network. The universal feature of networked control systems is that the component elements are spatially distributed, may operate in an asynchronous manner, but have their operation coordinated to achieve some overall objective. The proliferation of these systems has raised fundamentally new questions in communications, information processing and control dealing with the relationship between operations of the network and the quality of the overall system's operation [9].

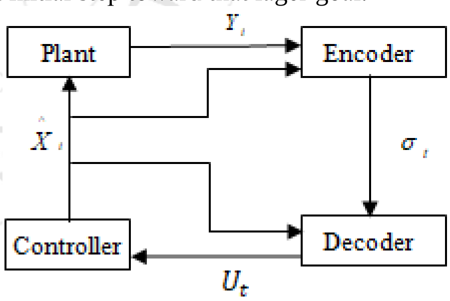
3. Mathematical Approach

The communication constraint will be modeled as a discrete – time, noiseless and digital channel connecting the sensor to the controller. For each time step this channel is capable of transmitting ***R*** bits without error. Our system should be satisfied to a necessary condition for examining of asymptotic observability and asymptotic stabilizability in linear discrete – time [14].

$$R > \sum_{\lambda(A)} \max\{0, \log|\lambda(A)|\}$$

The sum is over the eigenvalues of the A matrix.

Typical communication channels are noisy and have delays. A complete understanding of the interaction between control and communication will need to use tools both control theory and information theory. Understanding observability and stabilizabilty under communication constraints is an important initial step toward that lager goal.



Networked Control System

Now assumeing how to generalize the technique for state feedback to quantized output feedback. Assume the following system:

$$x(k+1) = Ax(k) + B(k)$$
$$y(k) = Cx(k) \qquad (1)$$

Where A and B are the same as before $C \in R^{1xn}$.

To assume a possible basic configuration for quantized output feedback which may lead to other more complicated settings.

Configuration: The control signal is quantized but the measurement is not. In the configuration, we assume that the controller is linear time-invariant with a finite order. It turns out that the configuration result in different quantization density requirements.

Theorem: To assume the system (1) with quantized control input. Suppose (A,C) is an observable pair. Then, the coarsest quantization density for quadratic stabilization by state feedback can also be achieved by output feedback. In particular, the corresponding output feedback controller can be chosen as an observer-based controller

$$x_c(k+1) = Ax_c(k) + Bu(k) + L(y(k) - Cx_c(k))$$
$$v(k) = Kx_c(k) \qquad (2)$$
$$u(k) = f(v(k))$$

Where is $f(\bullet)$ the quantizer as before, K is the state feedback gain designed for any achievable quantization density via quantized state feedback, and L is any gain which yields (2) a deadbeat observer.

4. Previous Attemps

Advent and development of the Internet combined with the advantages provided by NCS attracted the interest of researchers around the globe. Along with the advantages, several challenges also emerged giving rise to many important research topics. New control strategies, kinematics of the actuators in the systems, reliability and security of communications, bandwidth allocation, development of data communication protocols, corresponding fault detection and fault tolerant control strategies, real-time information collection and efficient processing of sensors data are some of the relative topics studied in depth.

A most critical and important issues surrounding the design of distributed NCSs with the successively increasing complexity is to meet the requirements on system reliability and dependability, while guaranteeing a high system performance over a wide operating range. This makes network based fault detection and diagnosis techniques, which are essential to monitor the system performance, receive more and more attention.

Many researchers and scholars have examined already. For examples, Elia and Mitter [19] examined the stabilizability problem in the case where the encoder is time invariant. They use a Lyapunov based synthese scheme to design the underlying quantizers. Liberzon and Brockett [20] have also examined a Lyapunov based design with time-varying encoders. They give upper bounds on the rate required to achieve stabilizability. A time-varying coding scheme is also present conditions under which these bounds are tight. Nair and Evans [12] give rate conditions for stabilizability of an ARMA model. They provide a rate condition similar to ours for insuring convergence. Baillieul [9] presents sufficient rate conditions for multivariate case with a single input and an A matrix with only real distinct eigenvalues.

5. Advantages and Disadvantages

Data network is being used in industry from quite a long time. The industrial areas for it include manufacturing, military, aerospace and automobiles. Introduction of control in networks for industry introduces lots of advantages. For instance: [10]

1) Flexibility: Network introduces the flexibility to control system and its resources. It enables to extend and share the network and its resources.
2) Reduced Complexity: Induction of control in networked system also reduces the complexity of system.
3) Data Sharing: NCS enables efficient data sharing as data is available on the network nodes when nodded.
4) Elimination of unnecessary wiring: it eliminates use of unnecessary wiring to build the large control system.
5) Remotely controlled. The ease of network allows the control to be done from remote side and make the vulnerable sites and protect operators. The NCS connect cloud (cyber) to the physical system which makes easy to control the side from distance.

The NCS utilizes the network so it inherent the problem of network into its structure. Some of them are listed below: [10]

1) Network Security: Data over the network can be available to everyone connected to the network if not properly handled. Special care needs to be one in order to protect the data over the network. Different cyber algorithm can be used to secure data. It becomes more crucial if NCS is connected to the internet. There are different means to protect the data then e.g., use of Virtual Private Network is one of them. [11]
2) Bandwidth Allocation: It is easy to extend the NCS because of network advantage but it can become problematic if there are bandwidth issues.
3) Network Delays: Because of data congestion the data may not be available when it is required and it feedback controller.

6. Conclusion

Despite all the achievements that have been made for networked control systems in the past decades, more efforts are still needed in the future. Most of these ongoing researches adopt the co-design methodology, and the collaborations between the control and communication as well as computation communities are desirable. These collaborations will then reveal the values of networked control systems in broader perspectives, by looking into its close relationship with other systems such as the Internet of Things, cyber-physical systems such, and multi agent systems. All these together then bring us the promising future of the networked intelligent automation.

References

[1] J. C. Maxwell, ''On governors," Philos. Mag., vol. 35pp. 385-398, 1868.
[2] T. D. Crouch, First flight: The Wright Brothers and the Invention of the Airplane. Washington, DC; Division Pub., Harpers Ferry Center Nat. Park Service, US. Dept. Interior, 2002.
[3] K.C. Lee, S. Lee, and M. H. Lee, "QoS-based remote control of networked control systems via PROFIBUS token passing protocol,"

[4] M. Farsi, K. Ratcliff, and M. Barbosa, “An overview of controller area network,” Comput. Control Eng. J., vol. 10, no. 3, pp. 113–120, Aug. 1999.
[5] Z.-W. Park and M.-K. Kim, “Design of an integrated fieldbus gateway,” in Proc. Russian–Korean Int. Symp. Sci. Technol., 2005, pp. 843–846.
[6] Z. Wang, H. Yu, H. Wang, A. Xu, and Y. Zhou, “The research of XMLbased extensible device description for FF fieldbus system,” in Proc. IECON, 2004, pp. 2600–2603.
[7] R. M. Daoud, H. M. Elsayed, and H. H. Amer, “Gigabit Ethernet for redundant networked control systems,” in Proc. IEEE Int. Conf. Ind. Technol., Dec. 2004, vol. 2, pp. 869–873.
[8] M. A. M. Vieira, C. N. Coelho, Jr., D. C. da Silva, Jr., and J. M. da Mata, “Survey on wireless sensor network devices,” in Proc. IEEE Conf. Emerging Technol. Factory Autom., Dec. 2004, vol. 1, pp. 537–544.
[9] John Baillieul and Panos J. Antsaklis, “Control and Communication Challenges in Networked Real-Time Systems,” Trans. Automat. Contr., vol. 95, No. 1, January, 2007.
[10] Seemal Asif, Philop Webb, Networked Control System – An overview, International Journal of Computer Applications(0975-8887) Vol.115-No6, April 2015, pp26-30.
[11] D.E.R. Denning, Cryptography and Data Security, 1st ed. Addison-Wesley Publishing Company, 1982.
[12] Girish N. Nair and Robin J. Evans, “ Stabilization of Stochastic Linear Systems with Finite Feedback Data Rates ,“ SIAM J. Control Optim. Vol. 44, No . 2, pp. 413-436. Society for Industrial and Applied Mathematics 2005. 2004.
[13] Girish N. Nair, Fabio Fagnani, Sandro Zapieri and Robin J. Evans, “ Feedback Control Under Data Rate Constraints: An Overview, “,“ IEEE Trans. Automat. Contr., vol. 95, No 1, January, 2007.
[14] Sekhar Tatikonda and Sanjoy Mitter, “ Control Under communication Constraints, “ Trans. Automat. Contr., vol. 49, NO. 7 July 2004.
[15] J.J.C. van Schendel “ Networked Control Systems Simulation & Analysis “ 2008.
[16] Fei Han, “ Analysis and Synthesis of Networked Control Systems with Limited Communication Capacity ,“ City University of Hong Kong, March, 2014.
[17] Menyue Fu and Lihua Xie, “ The Sector Bound Approach to Quantized Feedback Control,” Trans. Automat. Contr., vol. 50, No. 11, November, 2005.
[18] Julio H. Braslavsky, Richard H. Middelton and James s. Freudenberg, “ Feedback Stabilization Over Signal-to-Noise Ratio Constrained Channels,” Trans. Automat. Contr., vol. 52, No. 8, August, 2007.
[19] Roger W. Brockett and Daniel Liberzon, “ Quantized Feedback Stabilization of Linear Systems ,“ IEEE Trans. Automat. Contr., vol. 45, July 2000.
[20] Nicola Elia and Sanjoy K. Mitter, “ Stabilization of Linear Systems with Limited Information,” IEEE Trans. Automat. Contr., vol. 46, Sept. 2001.