Reduction of Data Losses and Packet Dropouts in Networked Control System Using H∞ Controller

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Abstract- *This paper presents an H∞ controller design method for networked control systems (NCSs) with bounded packet dropouts. Two types of state-feedback control laws are taken into account. Sufficient conditions on the existence of controllers for stochastic stability with an H∞ disturbance attenuation level are derived through a Lyapunov function dependent on the upper bound of the number of consecutive packet dropouts. A numerical example is finally provided to show the effectiveness of the proposed method.*

Keywords- H∞ Control, NCS(Networked Control System), Markov process.

I. INTRODUCTION

The packet dropout is one of the important issues, which results from transmission errors or congestion in the physical communication links or from buffer overflows. It is concluded that packet dropouts degrade system performance and possibly cause system instability.

Some criteria are proposed to check what the rate or the maximum numberpacket dropouts is to maintain the system stability. Various approaches to dealing with the packet dropout issue in NCSs have been reported in the literature during the last few years, such as using a Bernoulli process, switched systems. However, the number of consecutive packet dropouts is usually bounded by a finite number in practice. When the packets are successfully transmitted and received, the performance of the systems is satisfied according to the original design. Once a packet loss occurs, the performance is degraded. Then, it is a more interesting problem how many packet dropouts lead to system instability. The stability analysis and state-feedback control problem for NCSs subject to packet dropouts are addressed in, where the number of consecutive packet dropouts is limited by a known upper bound. In , an NCS with packet dropouts is The switched method can take into account the case of many consecutive packet dropouts by modeling them as independent subsystems. In all these aforementioned results, the dropout of a packet at the current time instant has no effect on the packet dropout at the next time instant. The process of packet transmission is mutually independent. However, there exist the effects of the current packet cases (dropped and received successfully) on the future packet cases. In the time interval between packet successful transmissions is used as a state in a Markov chain. The relations among the amount of consecutive packet dropouts are employed to establish the transition probability matrix. In, a Markov process describes the quantity of packet dropouts between the current time instant and the latest successful transmission. modeled as a switched linear system, and the controllers are designed by utilizing the theory of switched systems. In an average-dwell-time technique is introduced to model an NCS as a switched system consisting of some unstable subsystems to reduce the conservatism of the analysis and design results.

NETWORKED control systems (NCS) have received considerable attention in recent years. The interest for NCS is motivated by many benefits they offer such as the ease of maintenance and installation, the large flexibility and the low cost. However, still many issues need to be resolved before all the advantages of wired and wireless networked control systems can be harvested. Next to improvements in the communication infrastructure itself, there is a need for control algorithms that can deal with communication imperfections and constraints. This latter aspect is recognized widely in the control community, as evidenced by the many publications appearing recently.[4]

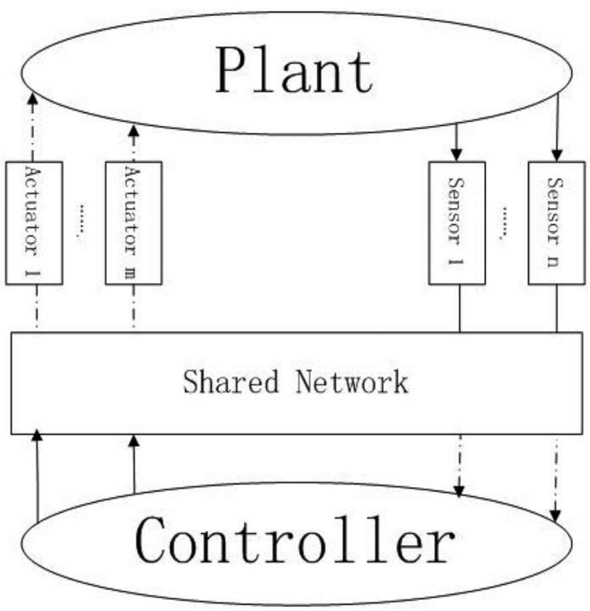
Roughly speaking, the network-induced imperfections and constraints can be categorized in five types:

(i) Quantization errors in the signals transmitted over the network due to the finite word length of the packets
(ii) Packet dropouts caused by the unreliability of the network
(iii) Variable sampling/transmission intervals
(iv) Variable communication delays
(v) Communication constraints caused by the sharing of the network by multiple nodes and the fact that only one node is allowed to transmit its packet per transmission.

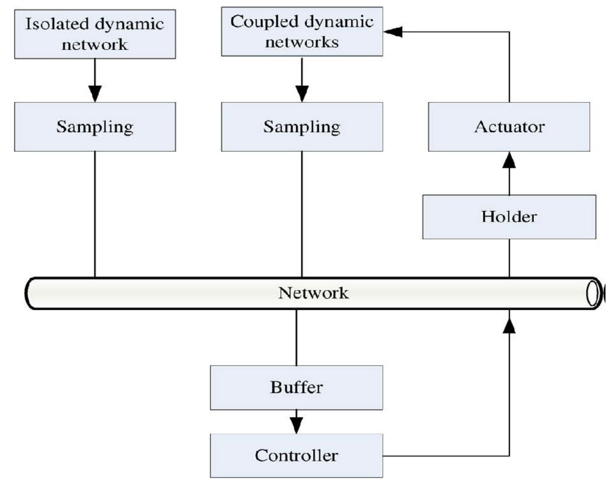
It is well known that the presence of these network phenomena can degrade the performance of the control loop significantly and can even lead to instability, see for an illustrative example. Therefore, it is of importance to understand how these Phenomena influence the closed-loop stability and performance properties, preferably in a quantitative manner. Unfortunately, much of the available literature on NCS considers only some of above mentioned types of network phenomena, while ignoring the other types. There are, for instance, systematic approaches that analyze stability of NCSs subject to only one of these network-induced imperfections. Indeed, the effects of quantization are of packet dropouts in, of time-varying transmission intervals and delays in, respectively, and of communication constraints.

Since in any practical communication network all aforementioned network-induced imperfections are present, there is a need for analysis and synthesis methods including all these imperfections.[3]

This is especially of importance, because the design of a NCS often requires tradeoffs between the different types. For instance, reducing quantization errors (and thus transmitting larger or more packets) typically results in larger transmission delays. To support the designers in making these tradeoffs, tools are needed that provide quantitative information on the consequences of each of the possible choices. However, less results are available that study combinations of these imperfections. References that simultaneously consider two types of network-induced limitations which are categorized.



Structure of non linear NCS



This brief tackles the problem of designing suboptimal controllers for linear networked control systems (NCS) subject to time-varying delays and packet dropouts. The formulation provides state feedback NCS controllers allowing to tradeoff performance and disturbance rejection. The control objective consists in designing ansuboptimal Control minimizing a quadratic performance index, with a disturbance rejection constraint (constraint). To characterize the network, only the lower and upper bounds for the delay, as well as the maximum number of consecutive dropouts are required. The approach relies on the formulation of the problem in terms of the minimization of a single scalar parameter, that can be cast as a standard linear matrix inequality (LMI) problem, yielding a suboptimal cost-guaranteed solution. As a difference from previous works, the solution provided is independent of initial conditions. Stability and robustness properties of the proposed controller are theoretically demonstrated and tested on an experimental testbed consisting in the stabilization of a robot arm in the proximities of the unstable upright position. The application shows good performance and disturbance rejection capabilities even for stringent network conditions.

CONTROL systems in which the different components (i.e., sensors, actuators, controllers) are connected through shared communication networks are called networked control systems (NCSs). Flexibility, low cost and easy implementation advise the use of wired or wireless shared networks in a great number of real-world applications. Most current control systems are based on a synchronous or quasi-synchronous scheme, where all signals are sampled uniformly and exchanged over dedicated links with known (or worst-case bounded) delays, and guaranteed data integrity. Nonetheless, in shared communication networks this paradigm is not always applicable and the design of controllers which operate in asynchronous, packet-based environments, needs to be addressed.[4]

Although some of these approaches tackle the design in the NCS context of controllers to the best of our knowledge, none addresses the problem of joint optimality and disturbance rejection. One classical approach to this is the control problem, where a given performance index is minimized, together with a -gain disturbance rejection constraint.

The control problem has been studied in some fields, as time delay systems, descriptor delayed system, neutral systems with delays , or observer-based control systems with time delays.[4]

However, to the best of our knowledge, there is no study concerning this issue for linear systems controlled through a network with induced time-varying delays and packet dropouts. Moreover, most existing results lack of implementation in realnetwork-based control systems.[8]

II. MODELLING

Consider the discrete-time plant described by
$x_{k+1} = Ax_k + Bu_k + B_2w_k$
$z_k = Cx_k + Dw_k$ (1)
where $x_k R^n$ is the state, $u_k R^m$ is the control input, $z_k R^q$ is the output to be controlled, and $w_k R^p$ is the disturbance input that belongs to $l_2[0,\infty)$. The matrices A, B, B_2, C, and D are of appropriate dimensions.

Assumption 1: The plant is stabilizable.
Assumption 2: The matrix B is of full column rank, i.e., rank(B) = m.
Assumption 3: The state information is measurable.
Assumption 4: The maximum number of packet dropouts is bounded and known.

A data-dropout rate is one of the important requirements of quality of service on all the aspects of a network, which is extensively studied under the assumption that it is bounded and known [7], [12]. It is characterized by bounded and known packet dropouts as well as the probability of packet drop outs in the data transmission [7], [11], [12], [19]. As observed in [7] and [11], bounded data packet dropouts (packet dropout probability in a Markov chain) are employed to quantify random packet dropouts. We consider the packet case at each time instant and a feedback configuration where the link between the controller and the actuator is a lossy network. The transmitted packets carrying the control information are stochastically received or lost. In general, the network transmission case at the next time instant is dependent on that at the current time instant. For example, when a packet dropout occurs at the current time instant, the probability of a packet dropout at the next time instant is larger than that of a packet receipt. Since a Markov process is able to describe the dependence of events, it is suitable to model NCSs with such kind of packet dropouts. In the following, the description of packet dropouts is given. Let u_k and. u_k represent, respectively, the input of the actuator and the output of the controller at time k. In addition, data packets are transmitted with time stamps to notify when they were sent. When the packet is received at the time instant k, then u_k= .u_k. Otherwise, u_k= u_{k-1} due to the existence of the zero-order hold at the actuator, which means u_k= .u_{k-1}, if the packet was received at the time instant $k-1$. Furthermore, if the packet .u_k is dropped out (i.e., u_k= .u_{k-1}), then, at time instant $k + 1$, there are three cases to be considered. In addition to the receipt and dropout of the packet .u_{k+1}, the packet .u_k may be received at time instant $k + 1$ (i.e., late arrivals, resulting in u_{k+1} = .u_k). The rest may be deduced by analogy. If consecutive $d - 1$ packets are dropped out, any of the dropped-out packets could arrive at the next time instant.
When the maximum number d of consecutive packet dropouts occurs, a packet dropout is not allowed any longer, and either the next packet or any of the dropped-out packets must be received. In this case, the process is a discrete-time homogeneous Markov chain taking values in $D = \{0, 1, \ldots, d\}$, where the states denote the number of consecutive packet dropouts. Note that 0 means that the packet is received, and d denotes the largest number of consecutive packet dropouts. Thus, the transition probabilities are described by and the transition probability matrix is as follows:

If the late-arrival packets are not and the transition probability matrix is as follows:

Remark 1*:* It is noted that (3) can model late-arrival packets. If a packet at the current time instant is dropped out but the previous packet arrives, the packet received is used to update the data. For example, in general, if consecutive d packets are dropped out, then the packet at time instant $k - d$ is used due to the existence of zero-order hold. However, in (3), if some packet sent between time instants $k - d + 1$ and $k - 1$ arrives late, it is utilized instead of the packet at time instant $k - d$. Apparently, the information in the late-arrival packet is newer than that provided by zero-order hold. The proposed model (3)has two advantages compared with that in [7]. First, (3) can model late arrivals of packets. Second, when late arrivals are not considered, the simplified transition probability matrix (5) has a much fewer number of nonzero entries compared with that in [7]. This is advantageous since in real applications, the nonzero parameters in (3) and (5) (i.e.,the probabilities) are approximated by statistics after a large number of trials, which can be a time-consuming process and requires significant effort. From this point of view, the model (3) is better than that in [7].In order to further lessen the workload to obtain the probability parameters, the model (3) is simplified as (5),where late arrivals are not considered. In this paper, based on the model (3), the problem of $H\infty$ control is studied.

A. Fixed Controller

In the sequel, using (3), the problem of designing a fixed-gain controller for NCSs is described, which is applicable in all the cases whether the packet drops or not.
The state-feedback controller is designed, i.e.,
$.uk= Kxk$(6)
Where K is a fixed gain that will be determined. For analysis purposes, the system states are augmented as]
and rk D denotes the number of consecutive packet dropouts.

When there exists a late-arrival packet, the number of consecutive packet dropouts has to be recalculated as the difference between the current time instant and the time stamp of the late arrival packet. For example, suppose that consecutive $rk-1 = dk-1$ packets had dropped out at time instant $k - 1$. When late arrival is not considered, it is obvious that $rk= 0$ or $rk= dk-1 + 1$. When taking into account late-arrival packets and supposing also that, at the current time instant k, the packet $.uk$is not received but the packet $.uk-l$, l $B= \{1, . . . , dk-1\}$
(which was sent out at time instant $k - l$) is received, then the number of consecutive packet dropouts is updated as $rk= k- (k - l) = l$, and the corresponding packet data $\xi rkiBK$in (7) is employed.

B. Variable-Gain Controller

When a fixed controller is not able to satisfy the control performance requirements in the presence of all possible packet dropouts such as stability and robustness, a variable-gain controller can be designed, whose value depends on the number of consecutive packet dropouts at that time instant, motivated by the idea of the switching controllers [21]–[23]. Since the number of consecutive packet dropouts can be obtained by a counter at the actuator, the switching signal is easily obtained and is dependent on the number of consecutive packet dropouts.

When one packet is dropped out, the counter is 1, and the controller$K1$ is active. When two consecutive packet dropouts happen, the counter is 2. If the packet sent at the previous time instant arrives, the controller $K1$ is active; otherwise, the controller $K2$ is active. When the largest number d of consecutive packet dropouts occurs, the counter is d, and the controller$Kd$is active. After that, the counter is reset to zero, and the controller $K0$ is active as the next packet will surely arrive (according to Assumption 4). In this case, the controller (6) is replaced with
$.uk= Krkxk$. (8)
Where $U \in Rn\times n$ and $V \in Rm\times m$ are unitary matrices, $\Sigma =$ diag $\{\sigma 1, \sigma 2, . . . , \sigma m\}$ is a diagonal matrix with nonnegative real numbers on the diagonal, and σj, $j = 1, 2, . . . m$ are nonzero singular values of B. Then, $BX = \Omega B$ holds for a nonsingular matrix X, if there exists Ω such that where.$\Omega 1 \in Rm\times m>0$ and .$\Omega 2 \in R(n-m)\times(n-m) >0$vThe objective of this paper is to design a fixed-gain controller (6) [a variable-gain controller (8), respectively] such that the closed-loop system (7) [(9), respectively] satisfies the following:

1) When $wk = 0$, system (7) [(9), respectively] is stochastically stable.
2) Under the zero-initial condition, it is guaranteed that
   $\_zk\_2$
   $E < \gamma 2\_wk\_22$
   for all nonzero $wk\in l2[0,\infty)$.

III. OUTPUT RESULTS

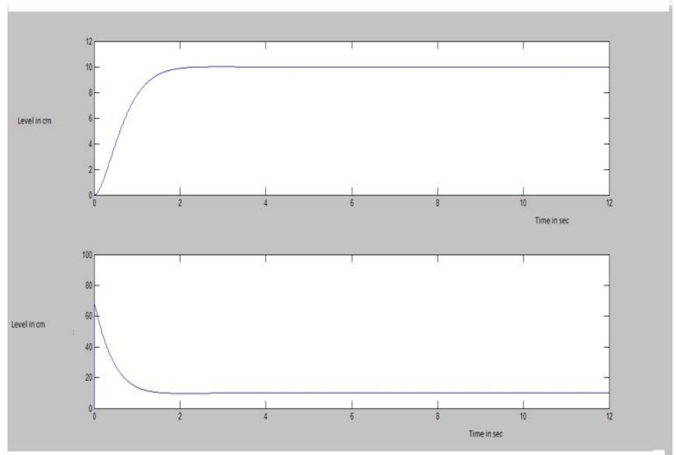


Fig:1 Output graph for the disturbance12

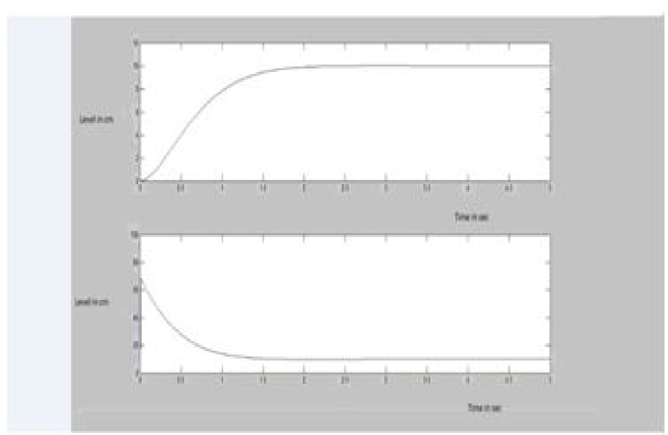


Fig:2 Output graph for the disturbance5

IV. CONCLUSION

In this paper, the NCS and its different forms are introduced. NCSs have been popular and widely applied for many years because of their numerous advantages and widespread applications .The *H*∞ control problem has the sufficient conditions for the existence of avariable-gain controller design have been presented to obtaina better performance index. Finally, the proposed method hasbeen illustrated by numerical simulations. Which involves the communication constrains and varying transmission intervals and varying transmission delay. That are controlled by the H-∞ controller.

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