Networked Control System – An Overview

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ABSTRACT

Networked Control System (NCS) is fetching researchers' interest from many decades. It's been used in industry which range from manufacturing, automobile, aviation, aerospace to military. This paper gives the general architecture of NCS and its fundamental routes. It also touches to its advantages and disadvantages and some of the popular controller which include PID (Proportional-Integral-Derivative) and MPC (Model Predictive Control).

General Terms

Networked Control System (NCS), Closed Loop, Feedback Loop, MPC

Keywords

NCS, Networked Control System, PID, MPC

1. INTRODUCTION

Integrated Systems is becoming major trends in industry which includes integration of computing, networks and control. It has been recognized that networks and control is becoming challenging research subject. It can be divided into two major parts first is the network challenges which includes handling congestion, speed, routing which is the area of control over networks it relates to controlling the problems in the network; the second the control of networked system or networked control system. This paper gives the summary of the second area.

Section 2 gives brief introduction about the Network Control System [1] and its implementation techniques. Proportional-Integral-Derivative (PID) is the basic controller to be used in control system which can handle the present, past and can predict future errors based on the information received. The MPC (Model Predictive Control) is well known and used in variety of industrial applications. It performs very well where speed, time and optimization are the issues. It has been proven in the case study for analysing and maintaining water level that MPC is better over PID where speed and performance is concerned. [2] MPC has also been used to deal with variable data losses and time delays in realtime environment. [3] which proves itself the most suitable method to be induced in realtime error compensation over the network.

To handle delays in network control system the observer algorithm was proposed. [4] It proposed the two feedback loop in the control system one for control system one for observer. They further used two more controllers for the anticipated and non-anticipated data.

2. NETWORKED CONTROL SYSTEM (NCS)

2.1 System to Control System

A system accepts some input process it and delivers some output. Figure 1 is showing the system which is accepting input which is signal for the system to produce the output in form of temperature. This system can be a heating or air conditioning system or any other system for which desired output is temperature.

Figure 1: System

If the output needs to be measured then it needs sensor to measure the output of system. For example for temperature thermometers can be used. Figure 2 is showing a common system with sensor to measure the output. The input to the system is usually called control effort and output from the sensor is called measured output. The Sensor measures the output of the system and can also convert the output into other form according to system requirement e.g., if the output from the system is temperature the sensor can be asked to convert into power / voltage (needed to produce that temperature).
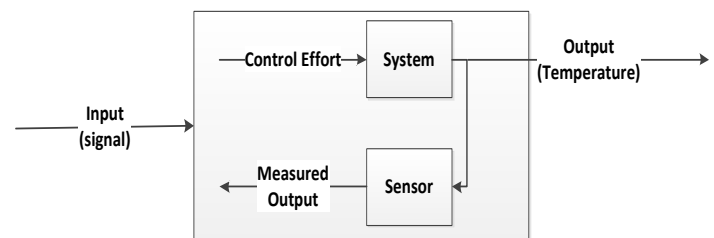

Figure 2: System with sensor

The input is the desired output or it's the output that is required from the system. So fabricated or calculated input needs to send to the system to get the desired output. To measure whether the output is the one which is desired a comparator is needed. The comparator compares the measure output with input. Inside comparator the measured output is usually subtracted from the input to maintain same output / controlled output from the system. is showing the system with sensor and comparator.
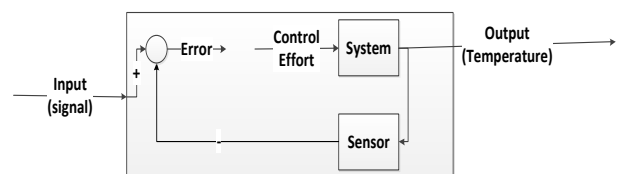

Figure 3: System with sensor and comparator (for Error)

This process results into error or an error signal which controller can use to control the plant / system. The controller uses the error information and input the system to get the desired output as shown in Figure 4. The control also controls the error and applies the computed control effort to the system.
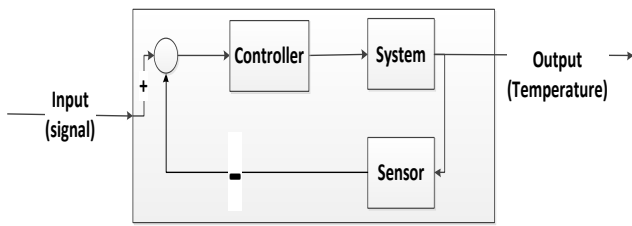
Figure 4: Control System - System with sensor and comparator (for Error) and Controller (for controlling Error)

2.2 NCS and its Types

As described in previous section about the control system. The control system is the one which produces and maintains the desired output of the system Figure 5 is illustrating the general control system.
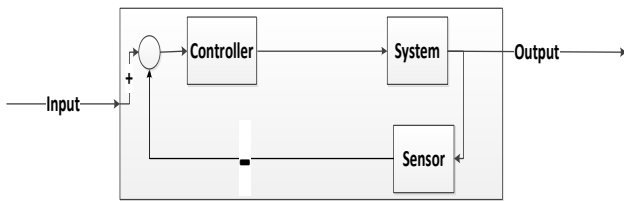

Figure 5: A Control System

The NCS involves the network between the control and the system. NCS is illustrated in Figure 6.
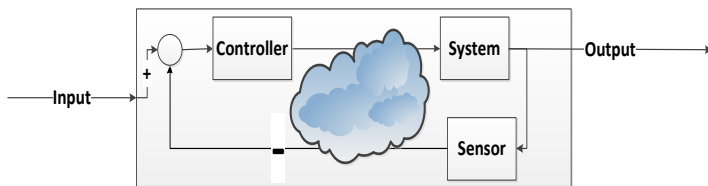

Figure 6: A Networked Control System

The introduction of network brings lots of advantages into the system itself but there are some demerits as well for using this mean of communication that is delay. The NCS or the Network Based Control System is the name of same concept that controls system over the data network.

There are mainly two general designs for NCS [5] i) direct and ii)hierarchical. [6] In direct structure the sensor is actually attach to the system (located at same place where the system is) and controller control the system over the network as illustrated in Figure 7.
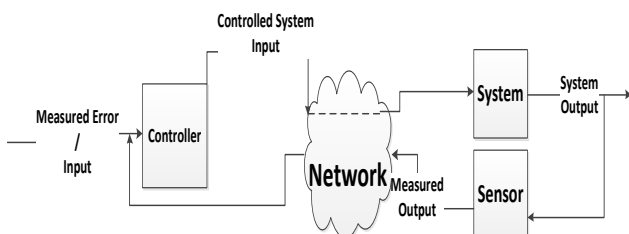

Figure 7: Direct NCS

The hierarchical NCS can have multiple subsystems which form hierarchical structure. This is illustrated in Figure 8. For each subsystem a Remote Controller is needed to control that subsystem and the global Controller control the output of complete system.
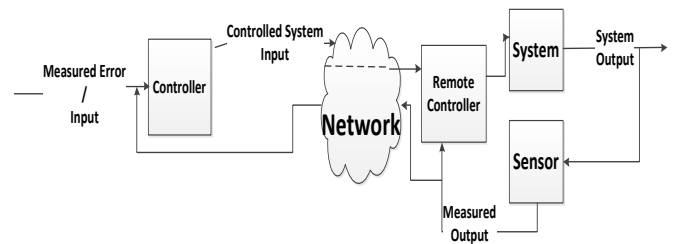

Figure 8: Hierarchical NCS

Both systems have their own merits and de-merits. Some systems use both of them to form the hybrid structure.

2.3 Advantages and Disadvantages of NCS

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. Some of them are listed below:

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 needed.

4. Elimination of unnecessary wiring: it eliminates use of unnecessary wiring to build the large control system.

5. Extendibility: it is easy to add more sub control systems and extend the network to attach them to central control system. When it comes to extend the system that can be done without massive changes to the physical layout of the system.

6. 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 site from distance.

The NCS utilises the network so it inherent the problem of network into its structure. Some of them are listed below:

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 cypher algorithm can be used to secure data. It becomes more crucial if NCS is connected to internet. There are different means to protect the data then e.g., use of Virtual Private Network is one of them. [7]

2. Bandwidth Allocation: It is easy to extend the NCS because of network advantage but it can become problematic if there are bandwidth issues. It can cause congestions and data which needs to be accessed by the network may not be available when it needed. High bandwidth infrastructure needs to be used to cater this problem.

3. Network Delays: because of data congestion the data may not be available when it is required and it

can introduce delay in whole network. There are many techniques which can be used to address this problem. Design of the system and network is first step to cater this problem. [8] Delays can destabilize the whole system if not handled appropriately. There are many controllers which can be used to address this issue and PID is one of them. [9]

4. Scheduling: Data traffic needs to be managed to get the required performance from the NCS. To utilize the bandwidth optimally scheduling can be done. Scheduling algorithms can be used to perform scheduling. [10]

2.4 Closed Loop / Feedback Loop

Loop is something that gets back and carries on repeating it-self. Loop (Open Loop, Closed Loop, etc.) is the integral part of any control engineering application. A system that needs to utilize any sort of feedback from the structure is a closed loop system.

The closed loop control system basic functionality is to get the desired output from the system using some controller / logic. In control engineering a simple closed loop is formed with an input signal, controller, output signal, sensor (to monitor the output of system) and the feedback loop. Figure 9 shows the basic architecture of closed loop system. The output of the system is measured by the sensor for inspecting any error or deviation from the desired output. The sensor also measures the effects of closed loop on the input of the system. This measurement is called closed-loop transfer function. [11]
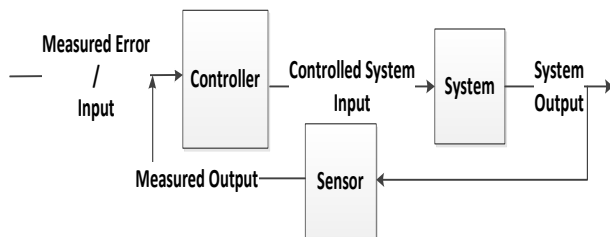

Figure 9: Basic concept of Control Closed Loop System in Control Engineering

The applications of closed loop ranging from a human body (control correct temperature of body, etc.) to home heating system, aircrafts, robotic manipulator, electronics, distance learning, automobiles, chemical industry and a lot more. Closed loop control system exists wherever there is input correction of the system to get our desired result. Everyone used it in their daily life like driving on the road and using correct pressure on the speed paddle to get desired speed.

For the feedback loop a communication mean is required and what if the system is using the network as means of communication.

2.5 Controllers

There are loads of controllers available in control engineering to control a particular system. Choice of controller purely depends on the system at hand. Some controllers are good at prediction while others are good at estimation. Some are used to cancel noise while others are used for the optimization of process. They are integral part of control system. Some of them are described below:

PID Controller: It's a very common controller which is used in control systems. PID is the acronym of Proportional Integral Derivative Controller. It is a generic controlled loop

feedback controller. In PID P (Proportional) determined by present error in the system, I (Integral) is the accumulation of past error and D (Derivative) is the prediction for future error. Error is the difference between set-point (SP) and measurement or manipulated value (MV). SP is the desired output and MV is the input vale to the controller. Equation

(Error! **No text of specified style in document.**-1) shows the PID algorithm in summarized form.

$$u(t) = MV\ (t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{d\ e(t)}{dt}$$

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Where

MV: Manipulate Variable or the measurement

$u(t)$: Controller output it is also measured variable (as input to controller) for feedback loop

e: $Error = SP - PV$ (PV is the process value which is initially equal to MV but then will be the output value of controller)

t: time at present

τ: its variable of integration

K_p: Proportional gain

K_i: Integral gain

K_d: Derivative gain

K_p, K_i and K_d are the constant values. They are called gains. Different results can be obtained by changing these constant values. Figure 10 is graphically illustrating generic PID controller.
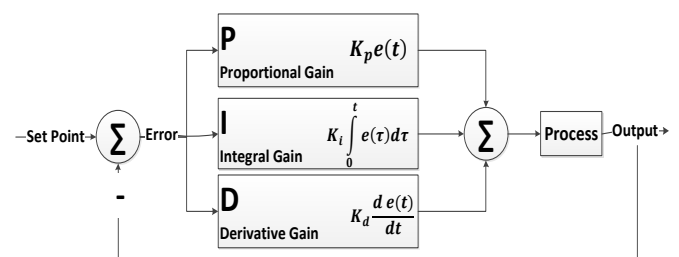

Figure 10: PID Controller

It's not necessary to use all of controls together some systems use PI others use PD or P or I. It all depends on the system and how it needs to be controlled. PID is very simple controller with simplest control design model. Indoor thermostat is the common example of PID Controller.

PID Controllers are commonly used in biological reactors, chemical reactors, thermostats, process industry, manufacturing industry etc. It is a very string controller and its demerits can be overcome by slight modification and induction of intelligence into the design of controller. [12]described ways to improve PID controller for using in

industrial systems. Robustness, performance, stability and noise/disturbance rejection are some of the advantages of using PID controller. The key is to use the correct type of PID controller for the system.

MPC controller: MPC (Model Predictive Control) uses process controller to predict the future behaviour / output of the system. MPC tries to optimize the behaviour of system at each cycle of calculation. It takes input and measured output (past) to estimate the current state of system. First time input is supplied to the controller and then it is always measured using the output of the controller. Input is always optimized to get the desired output from the controller. Figure 11 shows the conceptual model predictive controller.
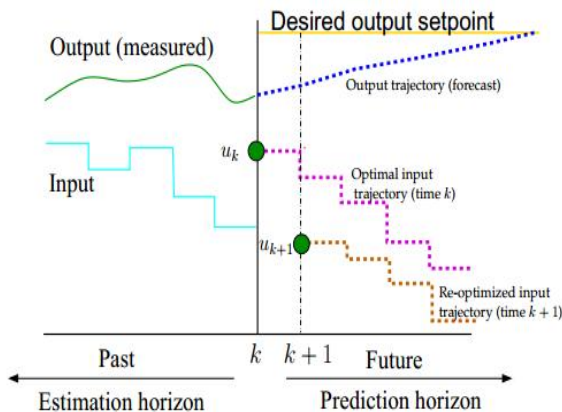

Figure 11: Conceptual model of MPC – open loop (Venkat, 2006)

MPC is used for estimation, optimization and prediction in the control system. Figure 12 described the MPC algorithm. Its algorithm is based on following:

1. Model of system under question (system to be controlled)

2. Bunch of conditions / constraints to be satisfied for example bandwidth limit or threshold values

3. The selection of decision variable

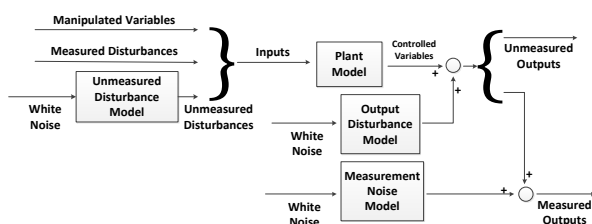4. State estimator flag to rebuild the model's internal state

Figure 12: Model Predictive Control Algorithm – MATLAB toolbox [13]

MPC was initially used in wind turbines, oil refineries, chemical and power plants but popularity of MPC attracted application areas from automotive, food processing, aerospace industry. [14]

MPC analogy is similar to chess game where the players decide move steps based on opponent move. Players forecast their moves and the opponent moves based on past and present moves. So there is online optimization at each move. Figure 13 is showing mapping of this analogy:
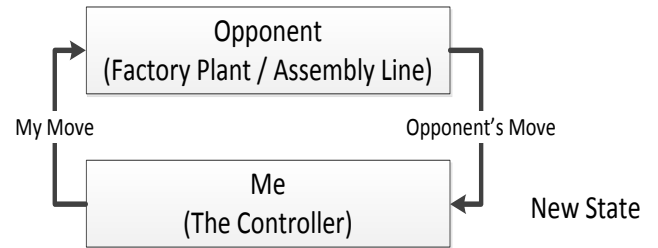

Figure 13: Chess game and MPC

Advantages of MPC include:

1. Flexibility to be used in various applications

2. Multiple flavours of model are available linear / non-linear, stochastic, fuzzy, distributed, deterministic, etc.

3. Most importantly calculation for the missing measure values / inputs which gave hint to use it to handle network delays

4. Capable to adapt changes in the system at runtime (or while running)

MPC also have some disadvantage like model uncertainty, low choice of variations in model, stability etc. Similar to PID it also has some variations and inductions of new concepts like distributed control, non-linearity, etc. [14]

3. SUMMARY
After analysing different kinds of NCS and its controllers it is clear that every technique has its own advantages and disadvantages. To apply certain technique it is very important to analyse the system and the network to find out the suitability and get the maximum advantage out of it. This review helped the research of the system which is under development in the Aero-structure Assembly and Systems Installation Research Group of Cranfield University.

4. ACKNOWLEDGMENTS

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