Implementation Of a Wireless Network Control System using smart Sensors-Actuator

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***Abstract*—An important class of NCS have been implemented over wireline and wireless networks these systems are known as networked control systems (NCS or WNCS) are attracting increasing research interest in the last decade. This is particularly relevant to the areas of communication, control and computing, where the successful design of WNCS brings new challenges for researchers. The main motivation of this work is to design and implement, recent guidelines for identifying problems and providing guidance through the successful implementation of WNCS. This paper describes the design and how have been its implementation, of a System Control Network Wireless and wired whose main characteristic is to use a shared medium that allows communication, using smart sensors and actuators configured with Arduino modules to control mechanisms: PID, PWM and on / off control, implementing a LAN so that it can monitor the behavior of two application processes through the cloud.**

***Index Terms*— WNCS, NCS, PID, networks, smart sensors-actuators**

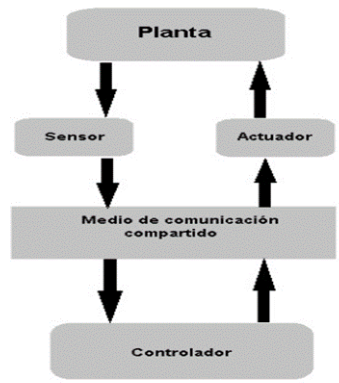

Fig. 1: Network control system with shared medium

I. Introduction

The industry has evolved according to the needs of new times with a market that demands their products rapidly, multiple processes must be continuously monitored and controlled. The conventional control systems use multiple means of exclusive communication between the controller and the various actuators and sensors field, the WNCS / NCS are characterized by using a unique means to communicate with all field elements, not only sensors and actuators but all device capable of obtaining an IP address or you can connect to internet As shown in Figure 1 control systems that use shared elements for communication between sensor elements, actuators and controller, ie, systems that use data networks for control loop or information networks based IP addresses are not in deterministic systems with periods asynchronous communication network. As there is a single means of comunication the number of devices compromise network efficiency by increasing the delay and other effects as described in [1],[2].

When performing a control system based on information networks, delays in data transmission between plant and controller have a negative influence on the control action, the controller's response tends to unbalance the system because it loses information variable interest until it is updated. The controller action depends on the time evolution of the variable of interest, many processes require real-time responses with high sampling values.

Possible configurations WNCS can be covered from two areas related to the system: communications area, taking into consideration the number of devices operating on the network with an appropriate value bandwidth, access to the media when certain requirements are met processes to avoid unnecessary use of network [3], control area, developing algorithms or strategies that respond to the absence of data by reducing the effect of the delays in the control system.

WNCS implementations are very few academic and industrial, especially in closed-loop control systems for working with fast dynamic loop. Many researchers have proposed different models that take into account NCS and may even reduce the effect of random delays in communication, as described in [4]. Among the different strategies a response arises in the absence of information from the network, the controller can interpret or guess the trend that could take the variable of interest by the physical characteristics of the process generating an alternative response. In introducing a solution of these characteristics, a unique algorithm for controlled compensation process unfolds. Another solution is highly relevant control systems for events [5] which is based on the dynamic evolution of the system to perform a control action, in conventional systems the advance of time defines actions processing and communication. The multiple benefits obtained from control events are basically the release of unnecessary workload for the controller and network because it is only necessary to make a response under certain system parameters and not in time

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II. Related Works

An important class of NCS have been implemented over wireless networks these systems are known as control systems in wireless networks (WNCS), they are attracting a growing research interest in the last decade. This is particularly relevant to the areas of communication, control and computing, where the successful design of WNCS brings new challenges for researchers. Generating so far studies, simulations but few applications as is mentioned in [3],[6],[7]

Today, developments that have taken communications networks has allowed networked control systems (NCS) are more robust with effective performance. In networked control applications that require a high degree of precision and flexibility, especially when computing resources are limited, it is necessary closer interaction between the two approaches. Given this close relationship between the control and communication network in a NCS, it is important to consider both parameters simultaneously as presented in [8].

Networks wireless sensor-actuator are different from the traditional network in various aspects, thereby necessitating protocols and tools that address the challenges and limitations. In [9] there is an extensive review of the literature in the period 2002-2013, in such works studies were presented on wireless sensor networks-actuators, which must consider the limited network resources.

In the development of this work we have improved the performance and utilization of communication resources. There is however, a growing awareness that the latency is now often the key to the user experience as limiting factor is mentioned in [10].

The infrastructure of the cloud and its broad set of resources available online, has the potential to provide significant benefits to automation processes presented in [11], where a survey about the potential benefits of the cloud is made, in improving automation processes, providing access to simulation tools; open source software.

III. Implementation of WNCS-NCS

A. System Architecture

The implemented client-server network is a communications network in which customers are connected to a server, where the various resources and applications that are available are centralized; and makes them available to customers whenever these are requested. This means that all the efforts being made are concentrated on the server, so that it requirements from customers having priority are arranged To design and implement a control system in wired and wireless networking, and software platform Arduino free hardware which presents multiple tools with great potential in different areas was used, this platform was adopted for its versatility and simplicity, allowing coupling modules Ethernet arduino that allows internet connection through Wiznet W5100 chip that allows you to work with TCP / IP protocols. The Ethernet arduino module can be adapted to different networks through its RJ-45 connector, working as a client making requests to different network elements or programming PAGES html server plus the dragino module yun that allows connectivity was used internet via Ethernet and wi-fi, so that the WNCS / NCS created must present friendly interfaces for different users entering the network, the different variables of the systems have a graphic record through an internet application. The

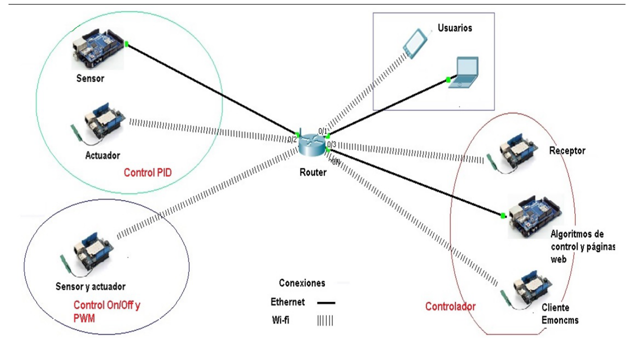

Fig. 2: W-NCS architecture implemented

different modules must meet its goal of maintaining acceptable error monitoring according to the process established as can be visualized in Figure 2. WNCS different devices can not have dynamic IP addresses, each network element sends specific information to a defined process, the DHCP protocol can provide several different directions to one device. You must define static addresses for each network element in the devices connected via Ethernet you can configure static addresses on the host itself, considering that the address belongs to the defined range, the devices that connect via wi-fi, DHCP define its parameters. To solve this problem you can define a fixed by the MAC address of the device IP address. When a new device enters the network sends data specific to the host, as the MAC address is unique to each device, establishing its fixed address.

B. Description of the Process Control.

NCS for creating two processes which are distributed the various intelligent sensors and actuators connected via Ethernet or wi-fi were taken to the central controller. The central controller also sends the values of the variables of interest to an internet application (Emoncms) for graphing and record its evolution. Each sensor and actuator has its own IP address that allows you to manage different data as a client or server. The network router configure features such as fixed addresses, passwords, MAC address recognition, connectivity with external networks and new users on the network.

1) ***PID control process****:* Ball-Beam is a system consisting of a ball can roll by tilting a surface which is connected to shafts with a servo motor. The position of the ball depends primarily on the angle of the servo motor, there are other parameters that must be considered as a system. Weight of the ball friction, the ball material and surface dimension shafts

Textbf Smart Sensor away Ethernet.- The Arduino Ethernet module must both receive information and distance sensor creates a server on a static IP address. The smart sensor is connected to the router, all network element can consult the distance value, the server has a program in HTML presenting this information. The distance sensor has an output that can not be expressed as a linear function, you must set certain conditions for the voltage-distance relationship.

Wireless intelligent actuator.-Yun Dragino must be set to the LAN to establish the characteristics of the device within the network. Wifi smart actuator is configured as a client which read different information from the central control, libraries Dragino Yun has other features compared Arduino Ethernet is because Dragino Yun works with other Linux-based processor. the HttpClient library is used to generate constant requests to the control center. The intelligent actuator PID process receives the values of the angle of the servomotor, this information is sent by the central generating a response in the corresponding IP address. The data are sent in String type variables, you must transform integer for later execution on the servomotor.

Process control algorithm with PID controller on the network.-

Algorithm 1 WCNS for the process PID

Server node PID Sensor

1. Parameter settings Arduino Ethernet communication
2. *Input*: $X_t^1 = \sum X_i^1$;Read requests client controller
3. X_i^1 ;Reading distance sensor
4. *Output*: $X_{i+\tau}$;Create html page with information measured variable

Client node Actuator

1. Communication configuration wireless Dragino Yun
2. *Input*: Z_t^1 ;Make requests to the server controller
3. $Z_t^1 = \sum Z_i^1$;Reads and stores information Driver
4. *Output*: $Z_{t+\tau}$;Send a signal to the actuator

Client-Server Node Controller

1. Setting Communication Server and Client Arduino Ethernet access in Dragino Yun
2. Creating user interface using html in arduino ethernet
3. *Input*:$X_t^1 = \sum X_i^1$;Make reading and distance sensor variable stores
4. $X_t^1 = X_t^1$;Linearization of the acquired signal
5. $Z_t^1 = \sum Z_i^1$;Information processing in the PID control algorithm
6. *Output*: $Z_{t+\tau}$;Send a PID value angle to the actuator

Present problems for the delays introduced by working in a non-deterministic network, have a serious effect on the stability of the PID station. It is considered an event every time data reaches the control center during this event this variable is introduced into the PID algorithm. Each event has a set period, depending on the efficiency of the response network can be reached in different time intervals (Asynchronous communication control). Separate samples of the PID station are not set by time, but by its own asynchronous action of the communication network.

*2) **Dyeing process and control On / Off**:* In the textile industry dyeing process has many problems in obtaining a homogeneous final product which retains all the dye applied. The temperature should vary slowly starting from 30 or 40 ^{circ} in a time interval, then the temperature must be increased in different variations of degree per minute, depends on the type of dye used. For pastel tones and light colors the top temperature is 80 ^{circ}, for all other colors is 92 to 96 ^{circ}, to ensure the successful migration of the dye to the wool was left to stand for 15 or 20 minutes at the top temperature. The theoretical foundation for dyeing wool is extremely extensive that merits a very thorough study to the process used in NCS only the temperature control that emulates the behavior of the temperature in a dyeing process is done. different times and temperatures reduced value for the application of PWM module and On / Off control is raised.

Sensor-Actuator.- Unlike Arduino Ethernet, Yun Dragino libraries facilitate interaction with the network, but data management undergoes processors have a very slow response for the linear programming. When making a request to a network server from Dragino Yun, while there is no answer or end the entire message, the following line programming is not executed. The temperature sensor LM35 is used to measure the process variable dye, which controls the temperature of a heater by switching on or off by a relay, a PWM output controls the engine speed, acting proportionately with system error. By including the various actions server-client, processor not implementing the actions that remain in the program until data transmission is complete. The various delays introduced by network range from two to three seconds, for this reason the action of fan speed control is not optimally met. Relay action is not affected, because switches in periods of four or more seconds. The fundamental problem lies in the response of the network, while the device I sent information request or does not complete this operation introduces a delay equivalent to having a variable time delay with the command.

Control algorithm dyeing process.- The measured variable in the dyeing process is not so volatile to an action, maintains some temporary stability. You can define the dyeing process as a slow reacting system. The control center is always receiving the temperature value of the dyeing process, however this update depends on the performance of the network.

Algorithm 2 WCNS to the process controlled ON/OFF

Server-Client node Sensor-Actuator ON/OFF

1. Communication parameter settings in Dragino Yun
2. *Input*: $X_t^2 = \sum X_i^2$;Read requests client controller
3. X_i^2 ;Reading the temperature sensor
4. *Output*: $X_{i+\tau}^2$;Create html page with information measured variable
5. *Input*: Z_t^2;Customer requests to the controller actuator
6. $Z_t^2 = \sum Z_i^2$;Reads and stores information Driver
7. *Output*: $Z_{t+\tau}^2$;Send a signal to the actuator

Client-Server Node Controller

1. Setting Communication Server and Client Arduino Ethernet access in Dragino Yun
2. Creating user interface using html in arduino ethernet
3. *Input*:$X_t^2 = \sum X_i^2$;Reading and storage of variable temperature sensor
4. $Z_t^2 = \sum Z_i^2$;Information processing in the control algorithm ON / OFF
6. *Output*: $Z_{t+\tau}$;Send time value relay switching

*3) **drivers**:* In the Central Control Arduino there are three devices that are connected together via serial communication.

In the Ethernet Arduino module are different control algorithms, creating pages that present information on the different variables of the systems, servers present data of actuators, data management between the Arduino cards Central Control. The two Dragino Yun wireless modules are responsible for receiving data and communicate with the Internet application for monitoring purposes and plotting variables captured by the sensors of various systems developed. Arduino Ethernet in the control unit is configured as a server with a static IP address, other ports are configured to make different pages that respond to the requests of the different elements of the systems. There are four Web pages that are developed in the central control, the purpose of each page is to contain some exclusive information for certain network elements: i) The first is the page presenting the general system information, the HTML code is the most extensive because it is the page that the user accesses to interact in the process. PID coefficients, etc.: a friendly interface to configure values as developed ii) The second page contains all information systems having an update every two seconds. Unlike the first page does not allow data entry. . iii) The third page contains the unique information of the PWM station and On / Off control has the values of PWM duty cycle and relay status. iv) The fourth page contains the unique information of the PID station.

IV. Model W-NCS implemented

Theory Network Control Systems are mathematical models in which this application is based, including those raised was considered [4] y [12]:

Control subject to induced time delay in the network.- If the communications network temporarily or permanently severe introduces time delays in the feedback path of the sensors through the controller to the actuators, the network may be modeled as a time delay system. Figure 3 total time delay in the feedback path is represented by tau [tau]. Therefore, the behavior of the network system on the left side of the figure can be represented as the time delay system shown in the right side where: τ = τ y + τ u In the shown

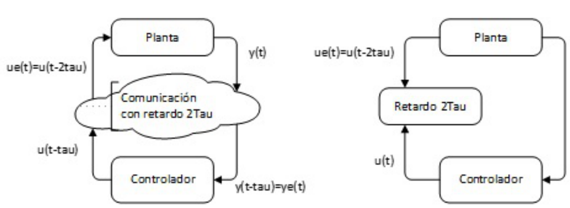

Fig. 3: Sistemas de Control en Red con retardo en la comunicación

structure, the network version ut) of the control input u (t) generated by the controller is delayed so that the overall system can be described by:

$$Planta = \begin{cases} \dot{x}_p(t) = A_p x_p(t) + B_p u(t+\tau) + E_d(t) \\ y(t) = C_p x_p(t) \end{cases} \quad (1)$$

$$Control = \begin{cases} \dot{x}_c(t) = A_c x_c(t) + B_c y(t) \\ u(t) = C_c x_c(t) \end{cases} \quad (2)$$

The systems theory known time delay can be applied to the analysis of this type of feedback systems. However, in networked systems, the delay tau is generally unknown. This fact has prompted further research into the systems delay time with stochastic delays in systems with delays described by the upper limits, and the systems for which the delay can be set online, as well as systems based control events.

Control with asynchronous communication and Computing.- In a further analysis, the components of job control loop schemes in different time event-triggered. Under the standard assumption of control theory of discrete time, all components work synchronously at the same time .This course is always satisfied that the time delays are small compared with the main time constants of the control loop If

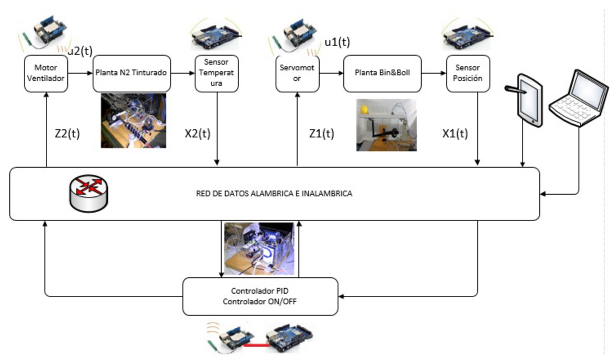

Fig. 4: Elementos asociados al modelo WCNS utilizado

the delays are larger, missing synchrony has to be represented in the model and leads to an interesting and important extension of discrete-time models. Suppose, for simplicity, there is only a delay between the sensor and the controller in the control loop, but the actuator receives the controller output without delay. Then, the actuator has to implement the entry:

$$u(t) = \begin{cases} u(k+1) & \text{for } kT \leq t < kT + \tau \\ u(k) & \text{for } kT + \tau \leq t < (k+1)\tau \end{cases} \quad (3)$$

where T represents the sampling time. In this formula, u (t) denotes the continuous signal in time and u (k) the k-th value of the discrete version of the input or time. Instead of getting the usual model plants sampled data

$$x_p(k+1) = A_d x_p(k) + B_d u(k) \quad (4)$$

$$y_k = C_p x_p(k) \quad (5)$$

Con

$$A_d = e^{A_p T}, B_d = \int_0^T e^{A_p \tau} d\tau B_p \quad (6)$$

Which it has two input terms with the matrix

$$B_{d1} = \int_\tau^T e^{A_p \tau} B_p y B_{d2} = \int_0^T e^{A_p \tau} d\tau B_p \quad (7)$$

In order to replace the two terms in the equation of state for the term of usual entrance, you can ”raise” the model by entering the entry as a new part of the state vector leading to model

Control and Communication Con-design.- In the co-design of the controller and the network planner, calendar of events of communication and calculation steps performed by the controller are selected at the same time. The main question that arises concerns the selection of the node that is allowed to send data at some point of time in order to stabilize an unstable plant or to optimize the performance of closed loop. If the sequence of sending nodes is denoted by

$$\sigma = (\sigma(0), \sigma(1), ..., \sigma(ke-1)) \tag{8}$$

and the sequence of control inputs by:

$$U = (u(0), u(1), ..., u(ke-1)) \tag{9}$$

the co-design problem can be formulated as the following optimization task:

$$J(x_0, \sigma) = \begin{cases} \sum_{k=0}^{k_0-1} (x^T(k)Qx(k) + u^T(k)Ru(k)) \\ +x^T(k_e)Q_e x(k_e) \end{cases} \tag{10}$$

V. Conclusions and Future Work

There are a number of obstacles and challenges in implementing a system control network with a shared medium, however the benefits obtained motivated several researchers to develop new methods and strategies, including breaking traditional control schemes. The main problem lies in existing communication delays between the different elements of a closed loop control, this is due to the own nondeterministic nature of the network. The value of the variation over time of the measured variable to a controller action, defines whether the control system is slow or fast reaction. Slow reaction systems can work with some degree tolerance delay time, but the rapid reaction systems controller response tends to destabilize the system

In information networks based on IP addresses there is always a random delay, for this reason the controller manages information both in the control and communications asynchronously, the concept of control events developed by the need to interact with the system not by units of time, but when an action requires a response. Many of the network resources are consumed unnecessarily driver when a conventional control system is performed.

It is recommended for future work to analyze the optimal functioning of a WNCS, the system must be subjected to various working conditions. Compensation algorithms have a certain limit on the delay time. When the network is presented with extremely high delays the algorithm must be attached to the new timeline. It should be borne in mind that delays can become a high value due to the number of nodes that consume bandwidth. The main objective would be to observe the WNCS functionality under extreme conditions of use of bandwidth and develop algorithms that provide optimal solutions.

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