TEST Engineering & Management

May – June 2020
ISSN: 0193-4120 Page No. 1708 - 1716

Network Scheduling By using Expert Nonlinear Controller

Rasha Shamit Salman[1], Ahmad T. Abdulsadda[2],
[1,2]Department of Technical Communication Engineering, Al Najaf Technical Engineering College, Al FuratAlAwast Technical University, Al Najaf,54001, Iraq.

Article Info
Volume 83
Page Number: 1708 - 1716
Publication Issue:
May - June 2020

Article History
Article Received*: 11August 2019*
Revised*: 18November 2019*
Accepted*: 23January 2020*
Publication*: 10 May2020*

Abstract:

A Researchers have increasingly concentrated on combining cellular networks with control systems, especially when the COVID virusedisster happened in these days and the human who is in the place with patients would be got the infection by the viruse, which is known as Wireless Network Control Systems (WNCS). At the other hand, these devices face many challenges and a time delay is one of those challenges. In this paper the WNCS architecture proposes the Fuzzy logic with the Proportional –Integral – Derivative (PID) controller,the optimal laws are achieved using the Particle Swarm Optimization (PSO) strategy. The ZigBee network used to transmit and receive data between the controller nodes and the device controls. The new controller aims to reduce the time delays which may keep the device safe in case of network overload. The tests obtained showed the controller suggested is keeping it is case stable although increasing the number of hostage nodes and the noise increased rapidly.
Keywords: *Dc Motor, Networking, Fuzzy theory, Optimization PSO, PID controller*

1. INTRODUCTION

Wireless technologies have been popular in many industrial applications where Wireless Network Control System (WNCS) has many advantages in terms of cost, great versatility and ease of maintenance, such as in all its parts controls, sensors, actuators and network[1-3]. A general network control system that uses in industrial systems is seen in Figure 1. Three problems when building power. The systems are networks of coordination, control theory and real-time applications[2]. While there are also some limitations in WNCS, such as packet losses, latency, communication security and reliability, limited bandwidth, development of various network protocols, and packet drops[3-5]. On the other hand, such as wireless networks in WNCS, for example,Further considerations should be considered for the control applications. WNCS does not need to optimize reliability for instance in control applications[4].

Abdul-Hussain et al.[5] The authors contrasted the two controllers PID and Fractional Order Proportional –Integral – Derivative (FOPID) based on the PSO algorithm in WNCS architecture in order to reduce time delays and to retain a reliable network. PSO is used to locate PID and FOPID controller parameters, and has checked the system with various loads. Wi-Fi is used as connectivity over cellular networks.

Sliding mode and PID controllers are developed by Salman et al.[6] for regulating DC-motor speed over the Zigbee network which is an NCS-based communication network and evaluating various network situations for both controllers, taking into account various Zigbee network parameters.Fuzzy logic developed by Peng et al.[7-10] to provide tuning parameters in a plant-based PID controller with second-order inertia and CSMA / CD (Ethernet) network connectivity mode. Aung et al.[8] ZigBee network Simulated by True-time based on MATLAB / Simulink network which transmitted data through the network between the PID controller and a DC motor. [8] The authors suggest using the conventional Fuzzy-logic PID controller and NCS Benefit Scheduling (GS). A wired network (Ethernet) is used as a link over the network. The F-PID-GS is tested with various load conditions and a randomization of packet loss. Such networks face the most important challenges.

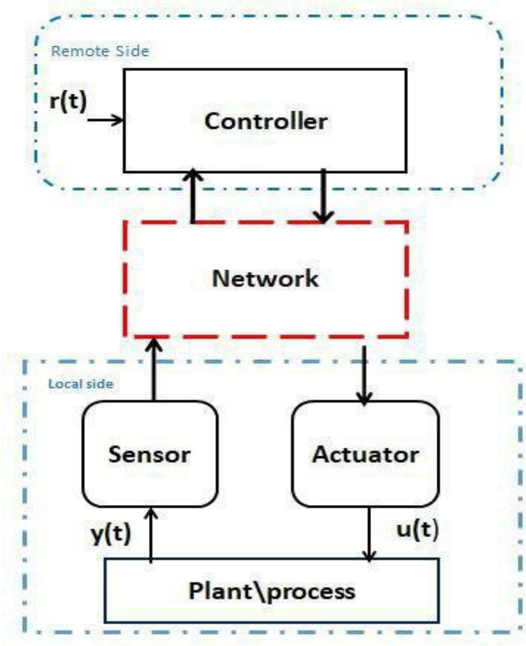

Figure 1: General schematic diagram of NCS, adaptive from [2].

A time delay at network congestion is one of these issues. Such issues are solved with a balanced configuration of the controller to ensure system efficiency and stability. The Fuzzy PID controller to wirelessly monitor the plant is proposed in this paper based on the PSO algorithm to find optimum rules for fuzzy logic, ZigBee network is used to connect monitor device pieces.

The remainder of this paper is arranged according to the following. Section II sets out the specification of the controller. Chapter III. Presents part IV of the real time toolbox. Presents the ZigBee network, while Section V discusses the proposed WNCS simulation, the proposed Fuzzy PID controller and PSO are discussed in Section V, Section VI. Experimental tests of the proposed methods. Section VII. Conclusion and discussion.

2. CONTROLLER DESIGN

A. PID controller

High quality performance and simplicity of nature have characterized the PID. It has three essential parts being proportional gain Kp, additive gain Ki, and differential gain Kd such that by tuning these parameters the efficiency of the controller could increase. Nowadays most of the PID controls are digital[10]. The continuous-time activity regulation of PID is expressed in equation (1) and equation (3) is shown as PID controller, The continuous-time operation function of PID is expressed in equation (1) and equation (3) is shown as PID function after Laplace Transform is taken for equation (1). Substitution S in equation (3) to equation (4)[11] is one way to get PID power in Z-transform.

$$u(t) = Kpe(t) + Ki\int_0^t e(t)dt + Kd\frac{de}{dt} \quad (1)$$

$$e(t) = y(t) \ - r(t) \quad (2)$$

$$U(s) = kp + ki\frac{1}{S} + kd\,S \quad (3)$$

$$S = \frac{2}{Ts}\frac{(Z-1)}{(Z+1)} \quad (4)$$

Where the control operation is u(t), the error signal is e(t), the relation is r(t) and the system phase output is y(t) and the sampling time is Ts. The PID controller still effective and cheap controller but the main problem it doesnot keep stable when the load increase and when the noise increase. This it happenes especially if we have complex situation and envirments.

B. Fuzzy theory

Fuzzy Logic is one logical form of decision-making such as a human decision that does not require specific knowledge of mathematical modeling. In 1965 LotfiZadeh suggested the word 'fuzzy logic'[9-12]. So the fuzzy logic theory is the transition from classical logic to several values between zero and one (expressed by truth or false),To become several values between zero and one, reflecting the transformation to metaphysical mathematics and linguistics. A general FLC structure is shown on fig. 2. To apply Fuzzy logic technique to a specific application it needs the following three steps, [9-13]:

May – June 2020
ISSN: 0193-4120 Page No. 1708 - 1716

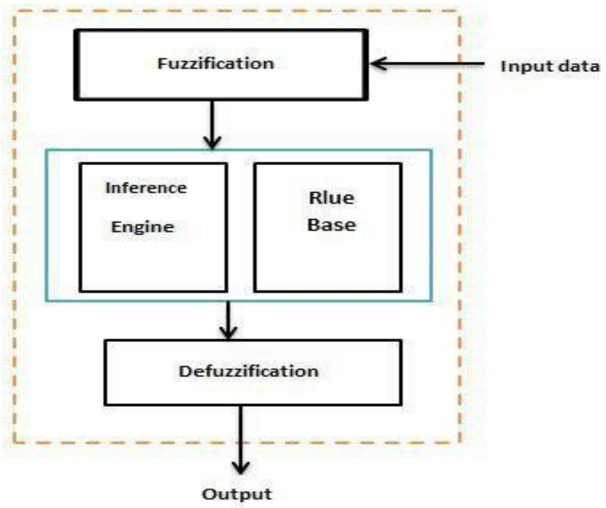

Figure 2:Schematic diagram of general fuzzy system.

• Fuzzification transforms flat or traditional data into Membership Functions (MFs) or Fuzzy Data.

• Fuzzy Inference System includes the integration of affiliation features with management rules.

• Defuzzification transforms fuzzy input into real output or input behavior to test each related output using various methods.

For its good success as a controller on the network, Fuzzy logic control technology has seen a great deal of development over the past few years. The area of design fuzzy controller for further stabilization mechanism is covered in several publications work. In fact, an FLC has a stronger control effect in non-linear and time-varying processes scenarios, comparable to a conventional controller or a classic controller, [10-14].Fuzzy logic control on our proposed architecture is used for an efficient benefit of the PID with a collection of Kp, Ki, and Kd depending on error and error change such that the Fuzzy logic input is error and error change and the Fuzzy logic output is the PID controller parameter. The parameter of the PID controller varies with the time, depending on Fuzzy logic rules. The mistake is high at the system's first moments and Fuzzy logic can give the machine a huge advantage. The Fuzzy logic adaptive advantage from a PID controller (n) controller or classical controller is shown in fig.3, [13-17].

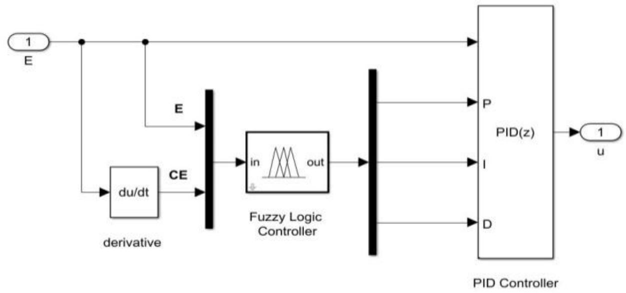

Figure 3: Fuzzy PID controller system.

Figure 3 displays the FLC which has two controller input variables namely error (e) and error derivative which is shift error and three output variables (Kp, Ki, Kd). The E and CE values within [-2 2] spectrum, each input and output have five memberships: NB (Negative Big), NM (Negative Medium), Z (Zero), PM (Positive Medium) and PB (Positive Big).For input and output, the triangular form memberships use the mamdani style in the inference process, and the centroid (center of gravity) technique used in the Defuzzification procedure. Writing laws of Fuzzy logic has become more practice and our idea uses PSO to determine optimum laws. The number rules are input number memberships power number and there are twenty-five rules at our work.

Table I: Fuzzy rule.

E / CE	NB	NM	Z	PM	PB
NB	PB	PM	NM	Z	PM
NM	PB	Z	Z	PB	PB
Z	PM	Z	NM	PB	Z
PM	NM	Z	PM	PM	PB
PB	NB	PB	PB	Z	NM

c. Particle swarm optimization

PSO is one of the most popular algorithms in literature style based on a population. Created and published in 1995 by Kennedy and Eberhart. It is influenced by animals 'social actions such as fish schooling or flocking of birds. The PSO is the same as evolutionary methods like Genetic Algorithms (GAs). Where the device is initialized with a random population matrix and generations updated to Look for the optimal solution. Unlike the Air, however, The PSO has no evolutionary

May – June 2020
ISSN: 0193-4120 Page No. 1708 - 1716

activities, such as crossover and mutation. The PSO has worked successfully in many study areas. It has shown excellent performance for the PSO in a quicker, cheaper way relative to other approaches. Another attractive aspect for PSO is that it has few criteria to change.PSO has been used for methods that can be applied in a wide variety of applications, and for different uses.In the PSO algorithm, for every solution of a problem, a particle is called, which can travel in a search field and change every particle location. PSO has two main vectors that are a velocity vector and a position vector. The location function determines the value of a problem solving solution. The Particle Location is modified using the equation (5) below.

$$Xi(\mathrm{t}+1) = Xi\,(t) + Vi\,(t+1) \qquad (5)$$

$$Vi\,(t+1) = w\,Vi\,(t) + C1\,r1\,(Pi\,(t) - Xi\,(t)) + C2\,r2\,(G - Xi\,(t)) \qquad (6)$$

Where the current and updated particle position is Xi(t+1), Xi(t), and the current and updated particle velocity is Vi(t+1), Vi(t). Pi(t) is the best solution for ith particles and the best solution for all particles inside the swarm is (G), r1 and r2 are random numbers within [0, l], C1 and C2 are two positive constants that control the impact of global and local PSOs.

Search capacities are typically equivalent to 2.and inertia weight is denoted w, which has a very significant function to control speed in PSO convergence behaviours. The PSO parameter is used in this article, as seen in TableII. PSO performance would be increased if the weight of the inertia is reduced linearly from 0.9 to 0.4 by the following equation (7)[16],Where Itermax is the average iteration in the evolution cycle, Wmax and Wmin are the average (0.9) and minimal (0.4) inertial weight values, and iter is the actual iteration value[14].

$$\mathrm{Wi} = \mathrm{Wmax} - \frac{(\mathrm{Wmax} - \mathrm{Wmin})}{\mathrm{Itermax}}\,\mathrm{iter} \qquad (7)$$

TABLE II: PSO PARAMETERS

Parameters	Value
C1	2
C2	2
Wmin	0.4
Wmax	0.8
Number of particle(n)	5
Number of iterations (itr)	25

A PID controller's fitness feature can include performance parameters such as rising (tr), settling (ts), overshoot (MP), and steady-state error (Ess)[16]. It should be noted that the concept of fitness function will differ from researcher to researcher;There is also no standardized way to describe the required fitness function within the PSO, given that each question has different fitness functions. The fitness function is used in this article, as seen in (8)[5-8].

$$J = \int_0^{-\infty} [w1\ |e(t)| + w4\,|e(t)|]dt + w3\ ts \qquad (8)$$

Answer ts will decrease by the word w3 ts where w3 will make the answer curve smooth. Also, the term w4 is punishment to avoid the overshoot of response. Where w4 is much larger than w1. The choice of parameters of w1, w3, w4 is very critical to find a solution to a problem. In PSO, each particle has several variables, so that each particle has seventy-five variables in this paper to represent a series of laws on fuzzy logic. To order the functions of one of the fuzzy logic outputs, seventy-five variables are split into three classes. The PSO -fuzzy PID performs the following steps:
1- Initialise the PSO function.
2- To spontaneously construct a population of particles.
3- Alter the flippant rules of logic.
4- Measure the function to fitness.
5- Measure the optimal solution and the latest iteration obtained for all particles.

3. COMUNICATIONZIGBEE PARAMETERS

ZigBee is one of the most important wireless solutions recently introduced, based on 802.15.4 specifications. It has several advantages including low cost, function of short delay time, low power consumption, and data rate. ZigBee occupies the upper layers of the protocol stack, where the layers Medium-Access Control (MAC) and Physical (PHY) are responsible for 802.15.4, [23-25] (shown in fig.4).

May – June 2020
ISSN: 0193-4120 Page No. 1708 - 1716

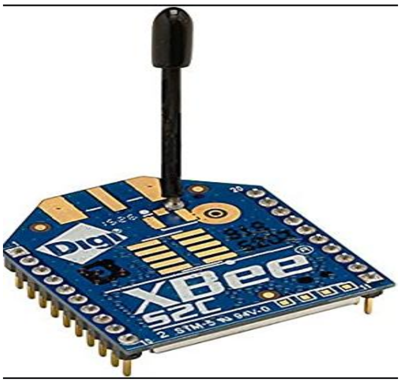

Figure 4: Zigbee hardware compoenet, [24].

The carrier sense multiple access with collision avoidance (CSMA-CA) is used to improve the probability of efficient transmission of data, [20]. The features of the Zigbee protocol include: allow for various topologies such as point to multipoint and point to point and mesh networks. In addition to the applications ZigBee provides, including remote control, building automation, surveillance systems,Remote meter reading and computer peripherals [21] To provide the following functionalities Zigbee has been developed:

1- Low installation and repair expenses.
2- For years, the ZigBee system battery does not have chargers.
3- The ZigBee wireless network has a coverage of 70 m indoors and 400 m outdoors.
4- For each frequency band the maximum data levels are 20 kbps for 868 MHz, 40 kbps for 915 MHz and 250 kbps for 2,4 GHz.For those reasons we have selected the Zigbee as one of the strongest communication device and it could be stable in the ronotic applications. True Time uses in this paper to model the parameters for the Zigbee wireless network [6] as seen in Table III. Every node has a position at a place where X and Y define the node's position. The position of the disturbance nodes to the sensor / actuator node tested in the experiment [21]. The direction of the sensor / actuator node is set to (60,0),The position of the controller node is (0,0) and the position of the interference receiver is (120,0) and the location of the interference transmitter is (20,0).

TABLE III: ZIGBEE PARAMETERS

Parameters	**Value & units**
Network Type	802.15.4(ZigBee)
Network Number	1
Number of Nodes	4
Data Rate	250000Bps
Minimum Frame Size	248 Bit
Transmit Power	3 dBm
Receiver Signal Threshold	-48 dBm

4. SIMULATION SETUP AND PRPOSED ALGORITHM

In this study, Figure 5 shows the proposed WNCS model which has two parts, the regulator node and the sensor / actuator node, linked via the wireless communication network (ZigBee). The regulator node has an input A / D and an output D / A. The regulator node receives a response device via the network, followed by an output on port D / A. Fuzzy PID process fault, and offer A / D port action power. The regulator transfers charge of the activity across a network. The sensor / actuator node has an input A / D and an output D / A. The sensor / actuator receives control of the activity through the network, and then outputs it to port D / A. The stepper motor that has the transfer function and all related parameters are taken from [23] is seen in equation (9) running and giving the A / D port response system.The sensor / actuator transfers monitoring activity over the network. Two Blocks of Interference are also used, one for the sender and one for the receiver. It aims to simulate the number of nodes loaded on the network, measure the effect of time-varying delays on the number of packets and calculate the average round trip time RTT between the sensor / actuator and nodes to the operator. So, the Intrusion sender node packet size is sent. As shown in Equation (10)[8].
PSO optimizer aims to determine the right fuzzy rules that the fuzzy can set the output to build on it so that PID can interpret parameters (KP, KI, and KD) as vector values. Time flies. On MATLAB 2018b and True Time 2.0 2016 our plan was simulating. where the Transfer function that is chosen is ctrical stable as following:

$$G(s) = \frac{1000}{s^2 + 3s} \qquad (9)$$

Packet length = (Nodes*BW share × Max P ×W) bytes (10)

May – June 2020
ISSN: 0193-4120 Page No. 1708 - 1716

Where the maximum packet size is MaxP, and the small portion of the bandwidth is BWshare, and a weighting index of BWshare (W) is a random number between (0, 1)[5].

There are two functions called Sensor task and Actuator task in the Sensor / Actuator network. The role for the Sensor would be based on an action dependent on time. The sensor function can detect the plant based on Shannon's Sampling Theorem per sample moment it measures. The Sensor / Actuator node performs plant output sensing, field calculation analysis,Prepare the sensor packet and deliver the sensor packet over the Zigbee network to the regulator node. The actuator function is based on the event-driven process, and reads the Zigbee controller packet.

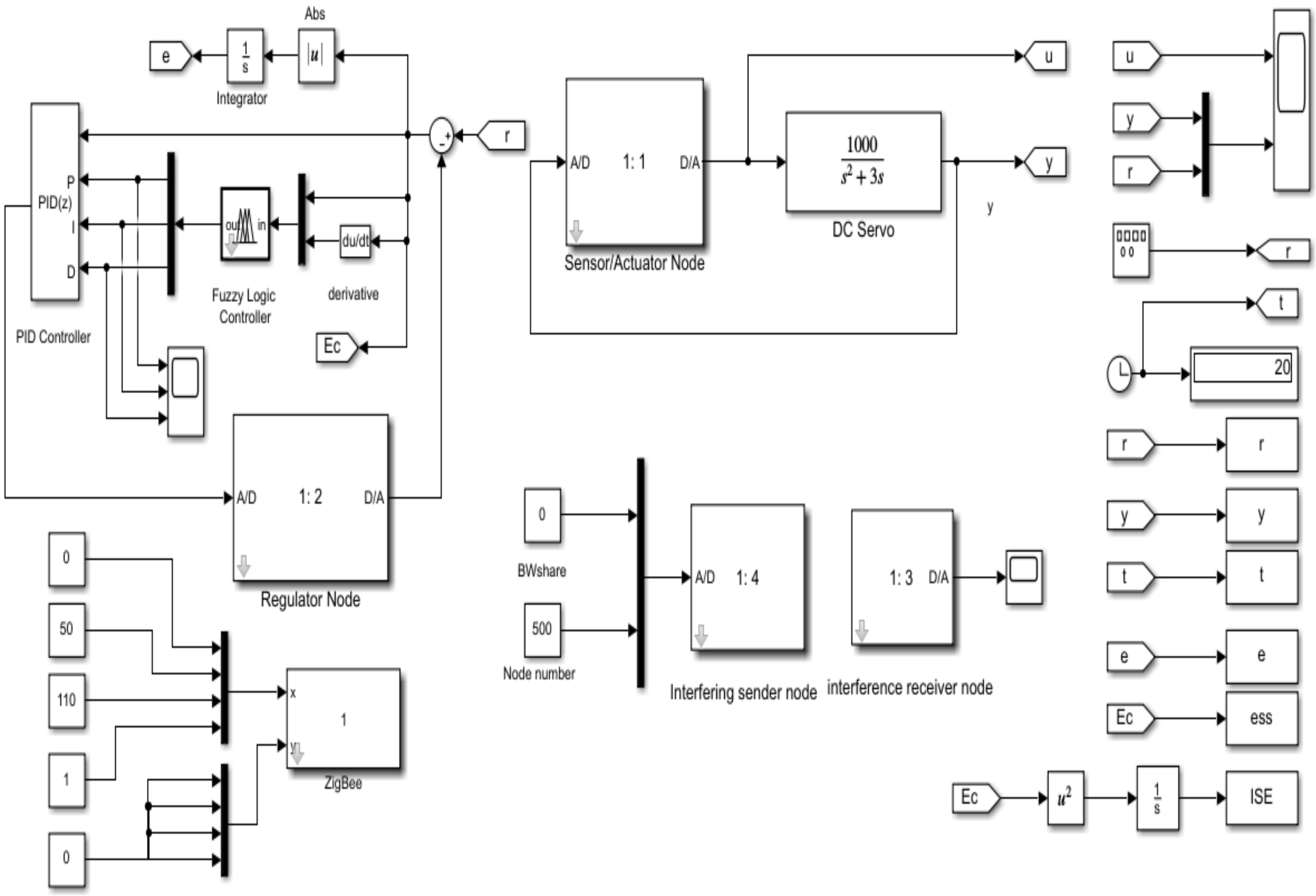

Figure 5: Prposed Simulink system.

The term NCS is a named that combines a network system and control system. All factors have to be taken into respect when designing NCS models or evaluating a controller algorithm so the NCS operates in the co-simulation field of network and control design. The co-simulation method uses TrueTime toolbox [17], shown in fig.6.

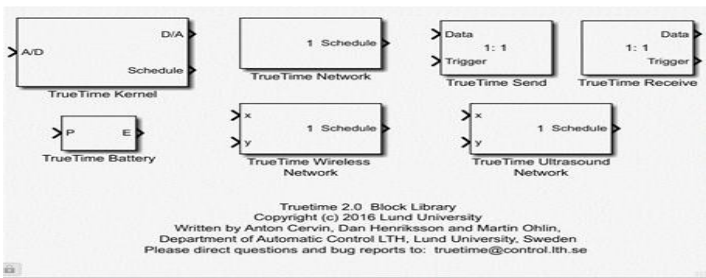

Figure 6: Main true time library that using to bulid up the system in fig.5.

The node controller or regulator has one task which is called the role of controller. It obtained the sensor signal from the Zigbee network interface, then this signal is interpreted by Fuzzy PID. The controller function would be based on the event-driven procedure and applied by reading the sensor packet from the ZigBee network interface, receiving a control signal, preparing the control packet,and sending a control packet over the Zigbee network. Figure 7 shows the algorithm followed by the sensor and actuator.And submit Zigbee Network Access Packet.

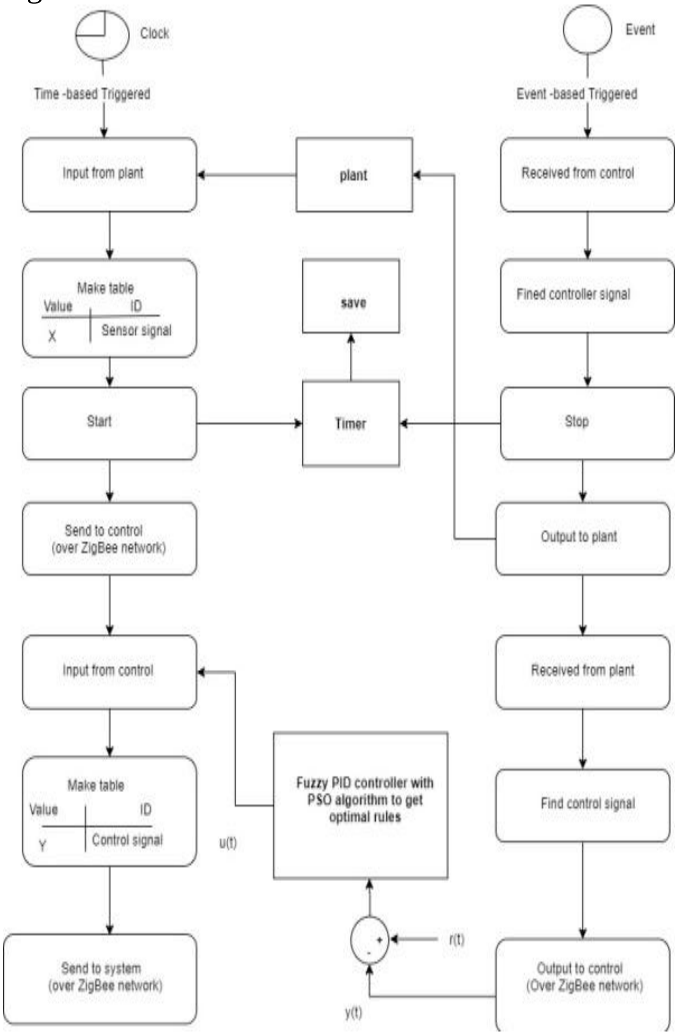

Figure 7: Prposed NCS PSO with fuzzy rule schematic algorithm.

5. Simulation Results

Case 1: PID with NCS network

The PID controller is a delay-free controller, meaning that the MA system inside the controller core should not be actualized. The PID additions pay no attention to the different system traffic conditions, these additions are tuned normally using MATALB capabilities (Kp= 20.8 range 10−3, Ki = 10 range 10−4, and Kd = 5 range 10−3). The system reaction of the PID controller alongside the control signal for empty (from 0 to 150 sec), medium stacked (from 150 to 300 sec) and high stacked traffic situations (from 300 to 450 sec) relevant to the relation is shown in Fig.8.

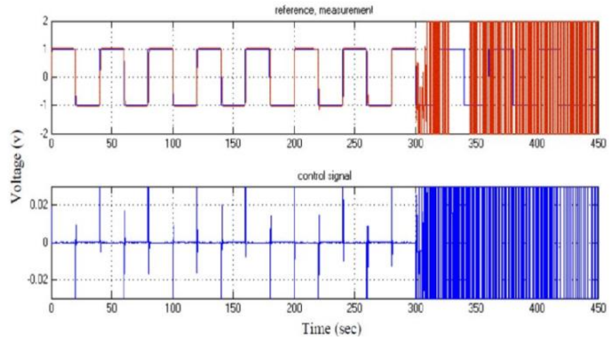

Figure 8: System response with PID controller, it takes (0-150 sec) where the system is unloaded network, after that at (150-300 sec) is a small loaded network is added, Finally at (300-450 sec.) the full load network.

Obviously, the main problem for this case PID controller with the networks is that, when the network is full loaded that make for sure the control action that steering the DC motor of the moving robot is noisey and uncontrollable and that would be making the robot going wrong by direction or behviour. Our objective is how solve this problem and keep the PID controller be given homegenouses decision control signal to the robot although there is noise and the networks is fully loaded. At that time the relabilty of using such scheme is increase and the probability of the robot goes wrongly become almost zero.

Case 2: In this case, firstly the PSO tuning the fuzzy rule member ship function as shown in fig. 9, Now with load of the350 nodes state from the Medium load network at BW share 0. 4 is tested. The WNCS contains Regulator Node, Sensor/Actuator nodes (350) emulated node that emulates in Interference sender node and interference receiver node so the total nodes in WNCS are equal to 350 nodes. A simulated packet length describes in (10) will be (350 ×0.4×133 × w) byte. In another word, the controller packet, sensor packet, and simulated packet will be sent via the wireless network. The system response stays stable with 350 nodes. The

May – June 2020
ISSN: 0193-4120 Page No. 1708 - 1716

Stepper Motor response and Action Control of Fuzzy PID controller are shown in fig.10. while fig.10 is a shown of the variable value of the parameter PID is changed periodeiclly with the control action to get the suitable performance and that would be helpful a lot to stabilize the system and control the DC motor that driving the robot, her the reabilty of the robot performance is clear strong enough what ever the distortion or the noise is the control still robustness.

6. CONCLUSION

With the COVID19 Viruse, remote mobile robots become is the only guid can be used to face this virus to be doing the testing and monitering the patients, In this paper we deomstrste the model proposed for WNCS. Any of the big challenges this program is facing need to be taken into consideration. One of these problems is different time delays which affect device efficiency and stability. Through designing a robust controller that manages the load on the network, particularly as the number of nodes increases, these problems are avoided.

In this article, it is proposed that the Fuzzy PID controller wirelessly control the stepper motor, and use the PSO algorithm to determine the optimum rules. This controller is checked when the device sampling time is 0.08 sec, when the sampling time in the intervening sender node is one sec, and can accommodate 350 nodes while BWshare is 0.4, respectively;

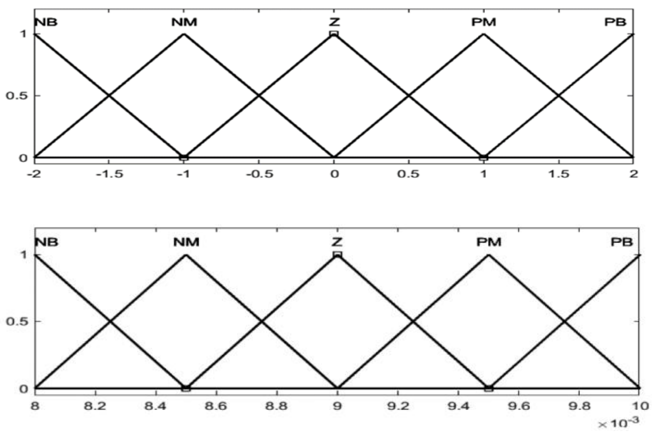

Fig. 9: PSO output membership function of the eroor and the Kp.

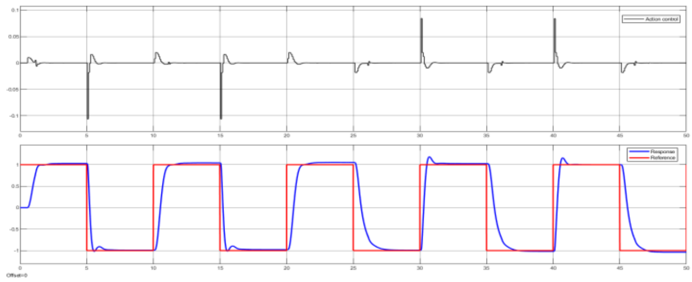

Figure10: Stepper Motor responseand Action Control of PSO Fuzzy PID controller, at Time sampling, =0.08s, BWshare=0.4, and N.of Node = 350 nodes.

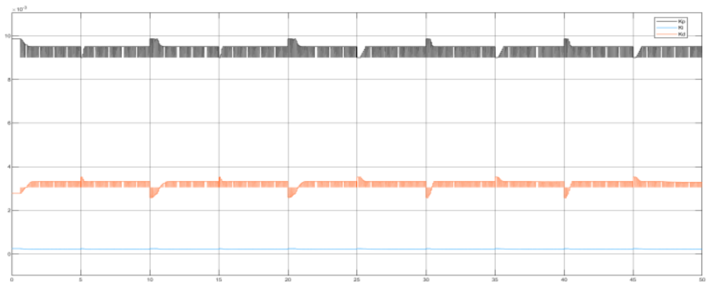

Figure 11 : Variable value of the parameter PID.

References

[1] Marie, Mehdi J., Ghaida A. Al-Suhail, and Salah Al-Majeed. "Client-server based wireless networked control system." 2016 IEEE East-West Design & Test Symposium (EWDTS). IEEE, 2016.

[2] Guo, Lejiang, et al. "The theory and architecture of network control system." 2010 International Conference on Intelligent Computing and Cognitive Informatics. IEEE, 2010.

[3] Tang, Xiao-Ming, and Bao-Cang Ding. "Design of networked control systems with bounded arbitrary time delays." International Journal of Automation and Computing 9.2 (2012): 182-190.

[4] Zhang, Dan, et al. "Analysis and synthesis of networked control systems: A survey of recent advances and challenges." ISA transactions 66 (2017): 376-392.

[5] Abdul-Hussain, Russul N., and Osama A. Awad. "Studying The Effect of Sampling Time and Network Load on Wireless Networked Control Systems." Journal of Al-Qadisiyah for computer science and mathematics 11.3 (2019): Page-31.

[6] Salman, Mais M., and O. A. Awad. "Evaluating a ZigBee Network with SMC for Hard and Concurrent Parameter Variations.",2017

May – June 2020
ISSN: 0193-4120 Page No. 1708 - 1716

[7] Deng, Jian-Qiu, et al. "Research on gain scheduling controller of the networked control system with long delay." International Journal of Control, Automation and Systems 13.1 (2015): 33-38.

[8] Aung, N., et al. "Simulation of Wireless Networked Control System Using TrueTimeAndMatlab." International Journal of Scientific and Technology Research 6.5 (2015): 31-35.

[9] Awad, Osama A., and IsraaLaith. "Gain Scheduling Fuzzy PID Controller for Distributed Control Systems." International Conference on Applied Computing to Support Industry: Innovation and Technology. Springer, Cham, 2015.

[10] Abramovitch, Daniel Y. "A unified framework for analog and digital PID controllers." 2015 IEEE Conference on Control Applications (CCA). IEEE, 2015.

[11] Starr, Gregory P. "Introduction to applied digital control." Lecture Notes in Digital Control (2006): 5-31.

[12] Czabanski, Robert, Michal Jezewski, and Jacek Leski. "Introduction to fuzzy systems." Theory and Applications of Ordered Fuzzy Numbers. Springer, Cham, 2017. 23-43.

[13] Jones, André, Arnold Kaufmann, and Hans-Jürgen Zimmermann, eds. Fuzzy sets theory and applications. Vol. 177. Springer Science & Business Media, 2012..

[14] Zadeh, Lotfi A., King-Sun Fu, and Kokichi Tanaka, eds. Fuzzy sets and their applications to cognitive and decision processes: Proceedings of the us–japan seminar on fuzzy sets and their applications, held at the university of california, berkeley, california, july 1-4, 1974. Academic press, 2014.

[15] Tharwat, Alaa, et al. "Particle swarm optimization: a tutorial." Handbook of research on machine learning innovations and trends. IGI global, 2017. 614-635..

[16] Li, Xu-zhou, Fei Yu, and You-bo Wang. "PSO algorithm based online self-tuning of PID controller." 2007 International Conference on Computational Intelligence and Security (CIS 2007). IEEE, 2007.

[17] Ogata, Katsuhiko, and Yanjuan Yang. Modern control engineering. Vol. 5. Upper Saddle River, NJ: Prentice hall, 2010.

[18] Cervin, Anton, Dan Henriksson, and Martin Ohlin. "TrueTime 2.0 Beta-Reference manual." Department of Automatic Control, Lund University (2010): 21-25.

[19] Wanga, Y., and L. Heb. "Analysis and Simulation of Networked Control Systems Delay Characteristics Based on Truetime." Computer Modelling and New Technologies 17.4 (2013): 210-216.

[20] Song, Chau-Chung, et al. "Simulation and experimental analysis of a ZigBee sensor network with fault detection and reconfiguration mechanism." 2011 8th Asian Control Conference (ASCC). IEEE, 2011.

[21] Hwang, Soyoung, and Donghui Yu. "Remote monitoring and controlling system based on ZigBee networks." International Journal of Software Engineering and Its Applications 6.3 (2012): 35-42.

[22] Cuenca, Ángel, et al. "A delay-dependent dual-rate PID controller over an ethernet network." IEEE Transactions on Industrial Informatics 7.1 (2010): 18-29.

[23] Peng, Chen, Dong Yue, and Min-RuiFei. "A higher energy-efficient sampling scheme for networked control systems over IEEE 802.15. 4 wireless networks." IEEE Transactions on Industrial Informatics 12.5 (2015): 1766-1774.

[24] Q. Ling, "Stability and Performance of Control Systems with Limited Feedback Information", Notre Dame University, Indiana, May 2005.

[25] K. Åström, and B. Wittenmark, "Computer Controlled System: Theory and Design", Third Edition, Courier Corporation, 2011.

[26] W. Zhang, "Stability Analysis of Networked Control Systems", Doctoralthesis, Case Western Reserve University, August 2001.