**An Open Access Journal Available Online**

# *Covenant Journal of Informatics & Communication Technology (CJICT)*

**Vol. 7 No. 1, June, 2019**

A Bi-annual Publication of the Departments of Computer Information Science, and Electrical & Information Engineering. Covenant University, Canaan Land, Km 10, Idiroko Road, Ota, Ogun State, Nigeria.



*http://journals.covenantuniversity.edu.ng/index.php/cjict*

**ISSN:** ***print*** **2354 – 3566** ***electronics*** **2354 – 3507**

Published by Covenant University Journals,
Covenant University, Canaanland, Km 10, Idiroko Road,
P.M.B. 1023, Ota, Ogun State, Nigeria

Printed by Covenant University Press

**URL:** ***http://journals.covenantuniversity.edu.ng/index.php/cjict***

## *Articles*

Proportional Integral Differential (PID) Controller
**Abdullahi Tekanyi, Angulu Rakiya & Kabir Abu-Bilal** **1**

Hybridized Intrusion Detection and Prevention System Using Static IP Address
**Oluwasogo Adekunle Okunade** **10**

A Review of Cluster Head Selection Schemes in Wireless Sensor Network for Energy Efficient Routing Protocol
**Ibrahim Rahman, Tekanyi A.M.S & Abu-Bilal, Kabir Ahmad** **21**

Graphical User Interface (GUI) for Position and Trajectory Tracking Control of the Ball and Plate System Using H-Infinity Controller
**Abubakar Umar, Zaharudden Haruna, Umar Musa, Shehu Aminu Mohammed & Momoh Omuya Muyideen** **35**

Optimized Industrial Automation Network for Efficient Productivity Using Quality of Service Policy Mechanism (QPM)
**Emmanuel Utochukwu Ogbodo & Ifeyinwa Faith Ogbodo** **57**

\\

**URL:** ***http://journals.covenantuniversity.edu.ng/index.php/cjict***

*Covenant Journal of Informatics & Communication Technology. Vol. 7 No. 1, June, 2019*

**ISSN: p2354 – 3566 e 2354 – 3507 DOI: 10.20370/V3G3-B013**

**An Open Access Journal Available Online**

# Proportional Integral Differential (PID) Controller

**Abdullahi Tekanyi, Angulu Rakiya & Kabir Abu-Bilal**

Department of Communications Engineering, Ahmadu Bello University, Zaria
1amtekanyi@abu.edu.ng, 2rakilira@gmail.com

**Received: 12.12.2018 Accepted: 15.05.2019 Date of Publication: June, 2019**

***Abstract***- Piezoelectric ceramics are used in many areas of applications. One of such areas of applications is in controlling electronic devices for accuracy and improved precision. Piezoelectric ceramics however have the problem of inherent high resonance frequency resulting in the piezoelectric ceramic suffering from hysteresis and delay in response to input parameters. PID controllers have been used in providing improved control and response to the piezoelectric ceramic so as to overcome the problem of hysteresis as well as the inherent high resonance frequency and slow response of the piezoelectric ceramic. However, PID controllers have the problem of overshoot as a result of sub-optimal selection of PID tuning parameters. PID controllers also take a long time in adjusting to changes due to error. This paper presents a firefly algorithm based PID controller (F-PID) for minimizing the effect of hysteresis in piezoelectric ceramics and also improving the response of the PID controller.

***Key Words***: Piezoelectric Ceramic, PID Controller, Firefly Algorithm, Hysteresis, F-PID

## Introduction

A piezoelectric ceramic is a material that has the ability to convert mechanical energy into electrical energy and vice versa(Xu, 2015). Piezoelectricity was discovered by Jacques and Pierre Currie in 1880. The piezoelectric material generates electric charge when subjected to stress. The application of an external voltage to the piezoelectric material causes a change in shape (Swallow et al., 2008).Piezoelectric materials play an important role in numerous applications in our everyday life. Some of these applications are found in optical devices, piezo buzzers in alarm clocks, in the medical field, in precision machines and many more(Ghiasi et al, 2016). Other areas of application include (Islam & Seethaler, 2014): semiconductor technology, sensors, actuators, reduction of vibration and noise, power transducers for high-power ultrasonic applications, piezoelectric motors, and photovoltaic.

Piezoelectric ceramics the inherent problem of slow response to changes in the input parameter, be it an applied voltage or a mechanical stress. It is therefore necessary to ensure that the response of the piezoelectric ceramic is optimal or at least near optimal in order to achieve increased accuracy and precision.

PID controllers are widely used in industrial control systems and few studies have been carried out on the use of these controllers for smart control (Zheng & Jiang, 2016). PID controllers are used in controlling piezoelectric ceramics with the aim of reducing hysteresis. Hysteresis is a phenomenon where a property of an electronic component or device lags behind changes in the variable causing it (Khadraoui et al., 2012). In other words, hysteresis can be seen as a dynamic lag between an input and an output that disappears if the input is varied very slowly (Etedali et al., 2013). PID controllers however, have some limitations. Some of these limitations include (Cai et al., 2010): large delay response and overshoots.

Several works have been proposed with the aim of overcoming the limitations of the PID controller. This paper presents a firefly algorithm based PID controller for controlling piezoelectric ceramics with the aim of minimizing hysteresis in the piezoelectric ceramic device.

## Similar Works

These reviews present similar works that show the extent of research work with respect to minimizing hysteresis in PID controllers so as to effectively control piezoelectric ceramics.

Khadraoui et al., (2012) proposed a H∞ (H-infinity) and µ-synthesis (micro-synthesis) approach to control micro-systems so as to ensure robust performance of the micro-systems. The controller synthesis was formulated as a set-inclusion problem. However, the H∞ produced fragile controllers, in that small perturbations of the coefficients of the designed controller caused hysteresis which led to an unstable control system. Etedali et al., (2013) carried out the development of optimal PD/PID controllers for semi-active control of isolated structures equipped with piezoelectric friction dampers. The controllers performed better than friction damper in terms of simultaneous reduction of floor acceleration as well as maximum base displacement. Xu, (2014) presented a digital sliding-mode control of piezoelectric micro-positioning system based on input-output model. The controller was established based on a linear digital input–output nominal model. Simulation results showed that the scheme was superior to the conventional PID control for motion-tracking tasks. However, the sliding mode control had the problem of high frequency vibration displacement which resulted in unstable systems. Islam & Seethaler, (2014) developed a sensorless position control technique for piezoelectric actuators using a hybrid position observer, which required neither an accurate inverse mapping nor a sophisticated charge amplifier in order to compensate for hysteresis. The use of sensorless positioning technique didn't take into account the external force that would have effect on the variables of the piezoelectric device hence it caused hysteresis in the result. Xu, (2015) designed a second-order discrete-time terminal sliding-mode control (2-DTSMC) strategy and its application to motion tracking control of a piezoelectric nano-positioning system. The issue associated with the technique was that the system state converged to equilibrium point asymptotically with an infinite settling time which resulted in instability in the system. Etedali et al., (2016) designed a decoupled PID control approach for seismic control of smart structures. The use of modal analysis didn't give real quantities for PID controllers as modal analysis included representing an n-order differential equation into 2n-first order state space form. This approach was therefore more theoretical and did not give accurate performance of a system in real time. Zheng & Jiang, (2016) presented a mutation particle swarm optimization (MPSO) PID controller. The controller was used to optimize the weighted coefficient of the Back Propagation network. The developed controller improved system dynamic performance and precision. However, the controller was unable to solve the hysteresis effect which exists in piezoelectric ceramics. Zheng et al., (2017) presented a systematic modeling and control approach for nano-manipulations of a two-dimensional piezoelectric transducer (PZT) actuated servo stage. The major control challenges associated with piezoelectric nano-manipulators typically include the nonlinear dynamics of hysteresis, model uncertainties, and various disturbances. Sun et al., (2018) proposed a piezoelectric micro-motion stage based on lever amplification mechanism. The external dimension was 57mm×57mm× 5mm. The stiffness coefficient of displacement amplification mechanism of the piezoelectric micro-motion stage was derived by using energy method. An experimental test system based on PID closed-loop control was established where an open loop hysteresis curve was obtained. Safa et al., (2019) studied an output feedback position tracking control problem relevant for a linear piezoelectric ceramic motor (LPCM). The main goals of the control design included achieving extremely high resolution, accuracy, stability, and improved transient performance when system uncertainties, unknown dynamics, and external disturbances acted on the system. Wang et al., (2019) presented a new precise positioning method for piezoelectric scanner of atomic force microscopy.

From these reviews, it is evident that extensive work has been done in addressing the problems associated with controlling piezoelectric ceramics and PID controllers as a means of addressing the response problems of piezoelectric ceramics. This paper therefore presents a firefly algorithm based PID controller for minimizing hysteresis in piezoelectric ceramics and improving the response of the PID controller. Performance evaluation will be carried out in terms of error jitter and by considering two input signals; unit step impulse and an exponential decay signal.

**Firefly Algorithm**

In this work, the firefly algorithm was used as an optimization tool to optimally select the best PID tuning parameters for the best control of the piezoelectric ceramic.

The Firefly Optimization Algorithm (FOA) is a meta-heuristic, nature-inspired, optimization algorithm which is based on the social (flashing) behaviour of fireflies. This flashing light can be associated with the objective function to be optimized. The firefly algorithm is based on three idealized rules which include (Yang, 2013):

1. Fireflies are attracted to each other regardless of gender.
2. The attractiveness of the fireflies is correlative with the brightness of the fireflies, thus the less attractive firefly will move forward to the more attractive firefly.
3. The brightness of fireflies is dependent on the objective function.

A summary of the firefly algorithm is presented below:

Objective function f(x), x = (x1,…, x2d)T

Generate initial population of fireflies xi (i = 1, 2, …, n)

Light intensity Ii at xi is determined by f(x)

Define light absorption coefficient,

while (t <MaxGeneration)

fori = 1 : n all n fireflies

for j = 1 : n all n fireflies (inner loop)

if (Ii <Ij), Move firefly i towards j; end if

Vary attractiveness with distance r via exp[- r]

Evaluate new solutions and update light intensity

**end for j**

**end for i**

Rank the fireflies and find the current global best g*

**end while**

Postprocess results and visualization

**F-PID Controller**

The developed F-PID controller presented in this paper is represented by the flowchart in Figure 1. The firefly algorithm was used in selecting the optimal PID tuning parameters that will result in reduced hysteresis in the piezoelectric ceramic as well as improving the response of the PID controller.

Using FOA, a population of fireflies (representing the PID tuning parameters) was initialized. The FOA was used to iteratively search among the population of fireflies for the firefly with the brightest light intensity. The firefly with the brightest light intensity represents the set of PID tuning parameters that sufficiently minimize hysteresis effect in piezoelectric ceramic devices. FOA does this search by moving from one bright firefly to a brighter firefly. This search process was repeated until the brightest firefly among the population of fireflies was achieved.

As earlier stated, performance evaluation was carried out in terms of error jitter reduction. Two input signals were used in testing the performance of the developed F-PID controller. A unit step impulse reference signal represented by Figure 2 and an exponential decay signal were used in this research work.

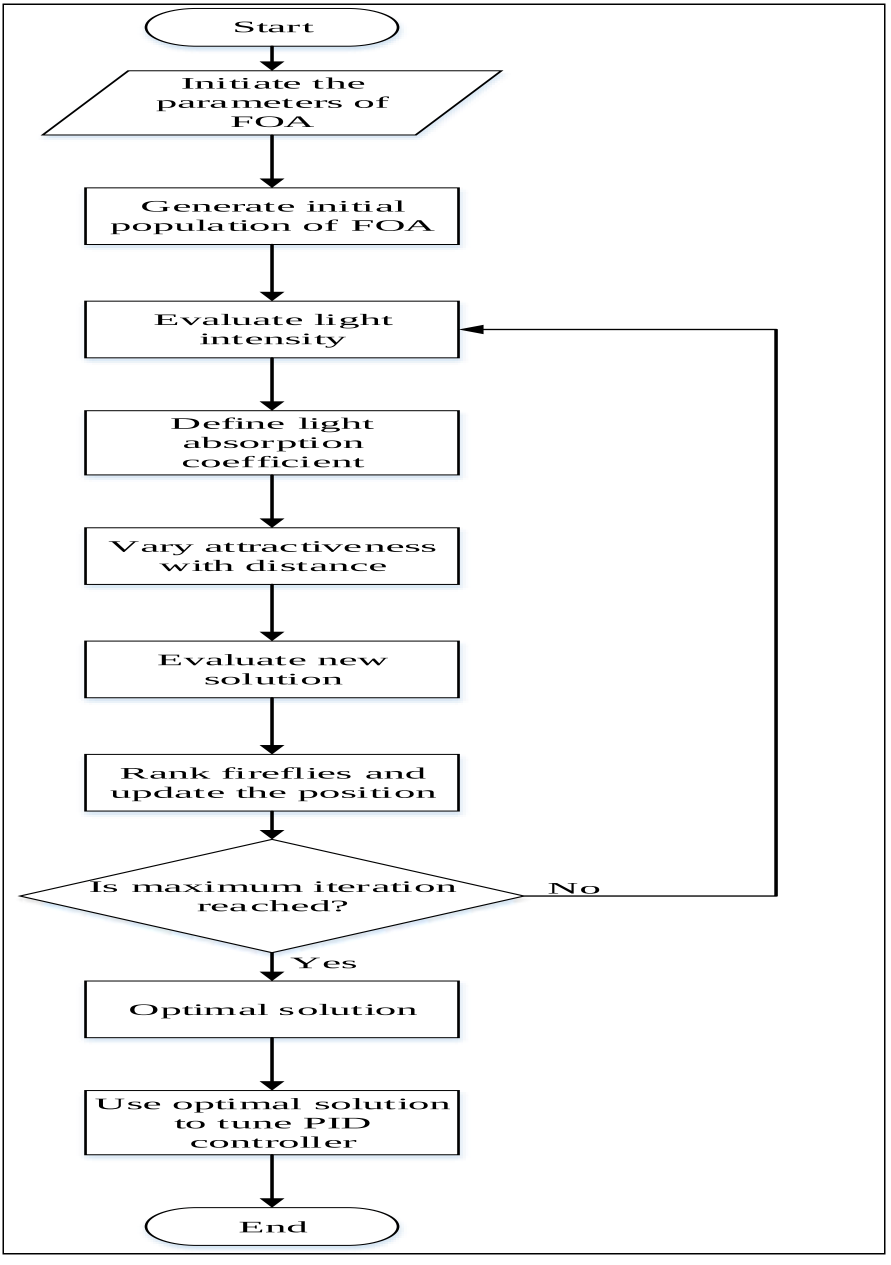



Figure 1: Flowchart of F-PID Controller

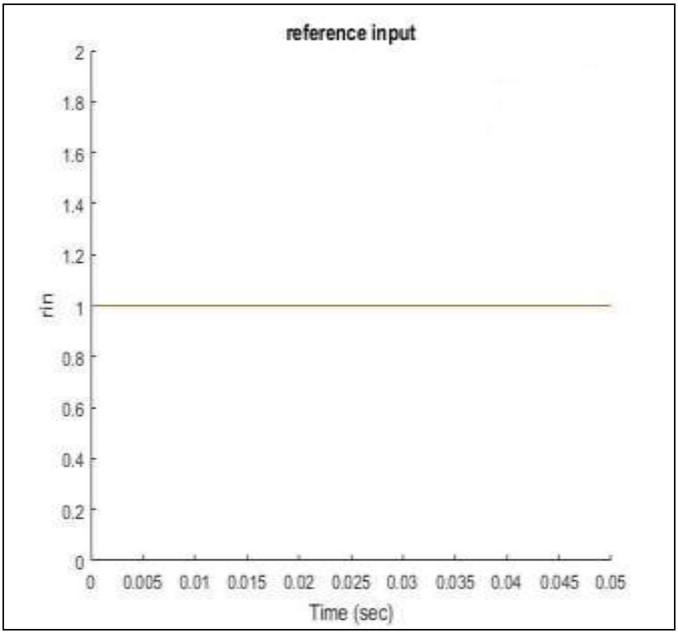



Figure 2: Unit Step Impulse reference Signal

The exponential decay signal is represented by equation (1).

$$r_{in}(k) = e^{-1.5 \times k \times ts} \times \sin(2\pi \times k \times ts) \qquad (1)$$

## Results and Analysis

The results obtained for this work are in terms of error jitter and it covers the two input signals used.

*Result for Unit Step Impulse*

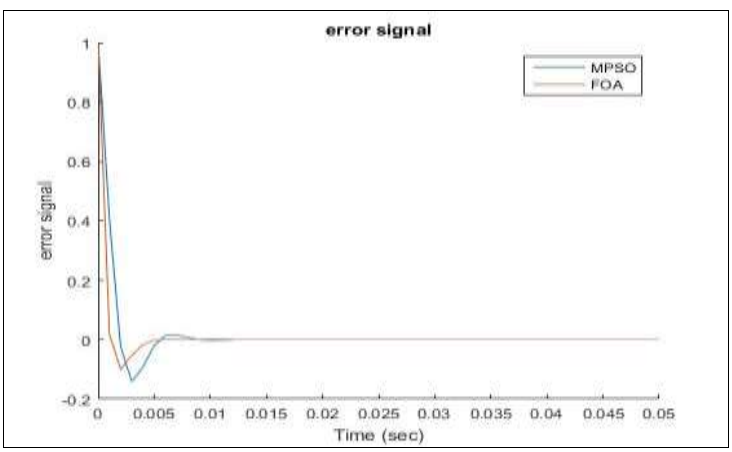



Figure 3: Error Signal Plot for Unit Step Impulse

Figure 3 shows the error plot of the system when the unit step impulse signal (from Figure 2) was applied to the piezoelectric ceramic controlled system. The desire for every system is to have an error that is equal to zero (error = 0). From Figure 3, the F-PID represented by FOA adjusted to the interference in the system faster than another PID controller that was based on MPSO. This improvement was as a result of the superior PID tuning parameters that the firefly algorithm obtained for the F-PID controller. This improvement translates to 37.5% in terms of reduction of error jitter.

*Result for Exponential Decay Signal*

The result for the exponential decay signal represented by equation (1) is presented in Figure 4. At time, t = 3.5s, interference was introduced into the input signal. The results obtained show how F-PID controller was able to adjust to this interference thereby keeping its error signal minimized.

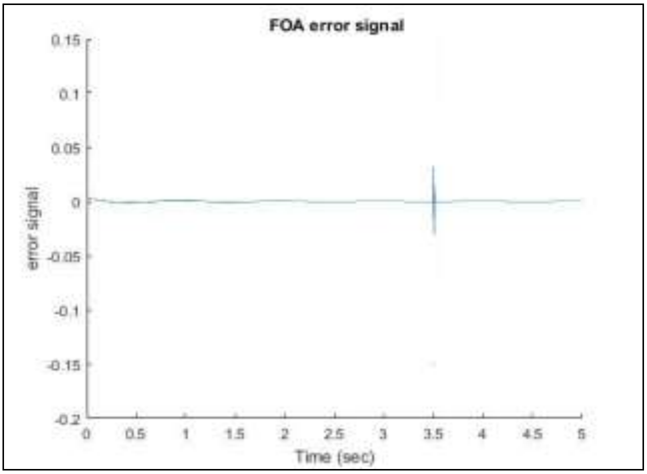



Figure 4: Error Signal Plot for Exponential Decay Signal (with F-PID Controller)

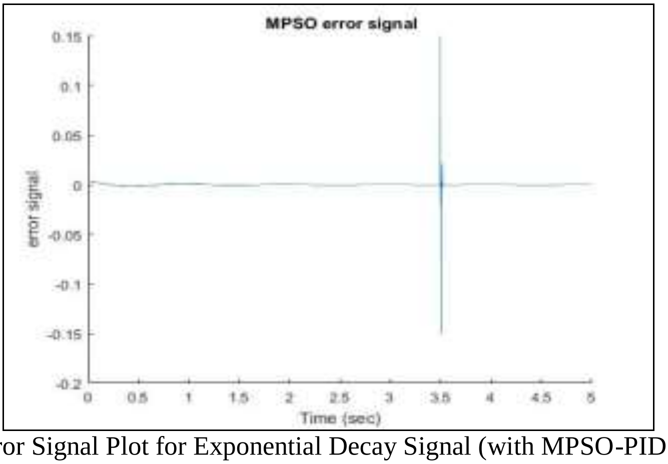



Figure 5: Error Signal Plot for Exponential Decay Signal (with MPSO-PID Controller)

From Figure 4 and Figure 5, both PID controllers have similar error plots. The error plots show that the two PID controllers were able to track and control the input reference signal (from equation (1)) by keeping the error in the

system at zero (0). However, at t = 3.5s, interference was introduced into the input signal, hence the spike observed in the error signals. F-PID adjusted to the interference better than MPSO-PID. This is seen from the Figure 4 which has smaller amplitude (0.03) and Figure 5 which has a larger amplitude (0.15). This improvement translates to an improvement of 80% in terms of reduction of error jitter.
The results show how the developed F-PID controller was able to adjust to an error in the system as a result of an interference at time, t = 3.5s (for the exponential decay signal).

## Conclusion

This paper presented a firefly algorithm based PID controller (F-PID) for piezoelectric ceramic control. Owing to the inherent high resonance frequency of the piezoelectric ceramic, as well as its slow response to changes in input parameters, a PID controller was used to minimize these challenges so as to mitigate hysteresis in the piezoelectric ceramic system. Firefly algorithm was employed in the PID controller to ensure optimal selection of PID tuning parameters so as to obtain efficient control of the piezoelectric ceramic system.

## Acknowledgement

This work was supported by the Department of Communications Engineering, Ahmadu Bello University, Zaria. All references used were duly cited and referenced in the reference section.

## References

Cai, J.-F., Candès, E. J., andShen, Z. (2010). A singular value thresholding algorithm for matrix completion. SIAM Journal on Optimization, 20(4), 1956-1982.

Etedali, S., Sohrabi, M. R., andTavakoli, S. (2013). Optimal PD/PID control of smart base isolated buildings equipped with piezoelectric friction dampers. Earthquake Engineering and Engineering Vibration, 12(1), 39-54.

Etedali, S., Tavakoli, S., andSohrabi, M. R. (2016). Design of a decoupled PID controller via MOCS for seismic control of smart structures. EarthqStruct, 10(5), 1067-1087.

Islam, M. N., andSeethaler, R. J. (2014). Sensorless position control for piezoelectric actuators using a hybrid position observer. IEEE/ASME Transactions On Mechatronics, 19(2), 667-675.

Ghiasi, H., Piltan, F., Avazpour, M. R., andHadi, M. (2016). Design Sensor-less PID Filter Controller for First Order Delays System. International Journal of Hybrid Information Technology, 9(4), 11-24.

Khadraoui, S., Rakotondrabe, M., andLutz, P. (2012). Interval modeling and robust control of piezoelectric microactuators. IEEE Transactions on control systems technology, 20(2), 486-494.

Safa, A., Abdolmalaki, R. Y., & Nejad, H. C. (2019). Precise Position Tracking Control With an Improved Transient Performance for a Linear

Piezoelectric Ceramic Motor. IEEE Transactions on Industrial Electronics, 66(4), 3008-3018.

Swallow, L., Luo, J., Siores, E., Patel, I., andDodds, D. (2008). A piezoelectric fibre composite based energy harvesting device for potential wearable applications. Smart Materials and Structures, 17(2), 025017.

Sun, F., Qi, S., Bao, J., Xu, F., & Zhao, W. (2018, August). Design and PID Control of Piezoelectric Micro-motion Stage. In 2018 IEEE International Conference on Intelligence and Safety for Robotics (ISR) (pp. 110-115). IEEE.

Wang, Y., Wu, S., Xu, L., & Zeng, Y. (2019). A new precise positioning method for piezoelectric scanner of AFM. Ultramicroscopy, 196, 67-73.

Xu, Q. (2014). Digital sliding-mode control of piezoelectric micropositioning system based on input–output model. IEEE Transactions on Industrial Electronics, 61(10), 5517-5526.

Xu, Q. (2015). Piezoelectric nanopositioning control using second-order discrete-time terminal sliding-mode strategy. IEEE Transactions on Industrial Electronics, 62(12), 7738-7748.

Yang, X. S., & He, X. (2013). Firefly algorithm: recent advances and applications. International Journal of Swarm Intelligence, 1(1), 36-50.

Zheng, H., andJiang, M. (2016). Mutation particle swarm optimization of the BP-PID controller for piezoelectric ceramics. Paper presented at the Seventh International Symposium on Precision Mechanical Measurements.

Zhang, Y., Yan, P., & Zhang, Z. (2017). Robust adaptive backstepping control for piezoelectric nano-manipulating systems. Mechanical Systems and Signal Processing, 83, 130-148.

Covenant Journal of Informatics & Communication Technology. Vol. 7 No. 1, June, 2019
ISSN: p2354-3566 e 2354-3507 DOI: 10.20370/xtjk-4b94

An Open Access Journal Available Online

# Hybridized Intrusion Detection and Prevention System Using Static IP Address

**Oluwasogo Adekunle Okunade**

Department of Computer Science, Faculty of Sciences, National Open University of Nigeria, Abuja, Nigeria.
aokunade@noun.edu.ng

**Received: 3.12.2018 Accepted: 16.04.2019 Date of Publication: June, 2019**

***Abstract***—Internet growth and constant increase in traffic volume, resulted into various misuse and attacks on the internet, that increases security challenges over intrusion detection and prevention system against sophisticated attacks. This has become paramount importance since single mode intrusion detection systems have a lot of difficulties in protecting system and network from sophisticated attacks. However, this paper propose hybridized intrusion detection and prevention system using static IP address whereby the incoming packets are examined for attacks at two layers, both at network level as network based intrusion detection and prevention system (NIDPS) and at host level as host based intrusion detection and prevention system (HIDPS) to further strength system and network security. This help to prevent against intrusion, minimize false positive and negative alert and maximize true positive and negative detection. This technique handled sufficient information in a real-time to account for irregular use of networks and computer systems in a real time.

Keywords/Index Terms— Security, Attack, Vulnerability, Network and filtering.

## 1. Introduction

Internetworking Protocol (IP) addresses are the unique numeric identifiers required of every devices connected to the Internet. It is a standard network layer protocol of the Internet architecture, that permitted communication within the various networks (Paulo & Joel, 2010). They are used for data routing across the internet. An IP address can be static (fixed) or dynamics (changes). Static IP addresses are specific IP addresses that are manually assigned by an administrator. Where dynamic IP addresses are not fixed but changes, automatically assigned by Dynamic Host Configuration Protocol (DHCP).

An intrusion is defined as violation of security policies that govern a particular system or network (Okunade, 2014). It is forcefully abuse or take advantage of someone's computer system or a network, with the intent of stealing personal information or reduce the functionality of a targeted system. This could be achieved through computer viruses, phishing, or other types of social engineering. Computer security is information security applied to computers and networks to monitor, control and prevent an unauthorized access to a system or a network, such as: hacking, Intrusion, data loss, data theft and data destruction, that are primarily internet security challenge (Jabez and Muthukumar, 2014 in Rajendran, Muthukumar and Nagarajan, 2015).

Intrusion Detection and prevention System IDPS is a network supervise or aware system, that primarily focused on identifying potential incidents. It is used to identify, examine, frustrate and report activities that are not consistent and tampering of data stored on the computer networks by unauthorized users. Intrusion Detection Systems (IDS) is also known as Intrusion Detection and Prevention System (IDPS) for it is configured to block any alleged anomalies without human interference. It is a real-time security detective and preventive system developed to discover violations of system security policy (Vani, 2016 and Srilatha, Ajith, & Johnson, 2004 and Dave, Trivedi & Mahadevia, 2013). It dynamically monitors the events taking place in a system, and recognize every symptom of attack (Debar, Dacier & Wespi, 1999 in Heba, Ashraf, Abouland & Ajith, 2018).

Single mode intrusion detection systems are not sufficient enough to safe guard dynamic level of today's network operations and activities due to the sophisticated means of attach that could be launch unaware. Single base IDS tools are notorious for false positives. However detecting sophisticated threats is very difficult for the single perimeter based IDS to be handle. According to Sandeep, Nishant and Pragya (2013) Network IDS monitor network traffic can raise an alert on suspected intrusion packets or act on those packets such as blocking and resetting concerned connections. It is a network monitor and alert system raises an alarm before the attack is being done and protects the system from various attacks (Ananthi and Balasubramanie, 2014 and Mehrnaz, Babak. and Iraj, 2018). An attack such as Denials of Service (Dos) are the most complex type of an attack to tackle, very easy to initiate and sometimes impossible to decline the requirements of the invader. However, an entry point of access security is highly required as an additional security support. Since the beginning stage research security focus that mostly lies in using statistical approaches and rule-based expert systems were not accurate, when encountering larger datasets according to (Manikopoulos and Papavassiliou, 2002 in Jabez and Muthukumar, 2015). Manu (2016) suggested that IDE can only be used as secondary wall of defense network security measure. As network growth and become complex, the IDE become weaker, as such, collaborative measure is highly required to strengthen the IDPS effectiveness. Remainder of this paper is organized as follows: Section 2 is the background of the work, Section 3 is the proposed algorithm and implementations, Section 4 describes the result derived from the given framework in Section 3. Finally, important conclusion is discussed in Section 5.

## 2. Background of the Work

### *2.1. Denial of Service (DoS) Attacks*

DOS attacks is a strong destructive attack difficult to deal with (Nadiammai & Hemalatha, 2014). It slow or shut down the target to disrupt services and deny authorized users (Manu, 2016). These attacks must be found and handled using an effective intrusion detection mechanism to detect and obstruct the attacks before implementation (Han and Wang, 2012). Intrusion detection mechanism classify packets as either legitimate or malicious, having carefully examine the packet (Osanaiye, Cai, Choo, Dehghantanha, Xu, & Dlodlo, 2016).

### 2.2. Intrusion Detection System IDS

Intrusion Detection System IDS is a software that monitors network activities for abnormal detection or violation of system or network established policies. It was introduced to avoid security inaccuracy and false alarm rate (Shamshirband, Anuar, Kiah, Rohani, Petković, Misra and Khan, 2014). IDS consists of review data collection agent that gathered information on the observed system, for storage or decision making having analyzed the gathered information Muamer and Norrozila, 2012). It could be destructive, if vital information (Such as personal, company, credit card details and others) could get into the hand of an intruder. Meaning that it is achievable that normal user's account on the machine can be adequate to cause damage (Shaik, Rao and Chandulal, 2010). According to Sonali, Madhuri, Jyoti, Sunanyna and Patil (2017) function of an IDPS is to offer protection to spread computing environments which are controlled and managed by a particular network. IDPS perform confidentiality as a function in the sense that authorized users are only allowed to access the information. Integrity which is the trustworthiness of information and data, consistency and availability of information only to the authorized users.

Therefore, IDS is highly required with the qualifications of identifying known and unknown attacks with little or no false negative or positive rate for effective intrusion detection. IDS is a collective tools, methods, and resources that help to identify and report intrusion in a system or network (Ismail, Salvatore & Ravi, 2013). Prevention of a system or network compromise of: confidentiality, availability and integrity of the system, data stored and control are the main function of an IDS (Alex, David and Aladdin, 2018). Network is any set of interconnecting lines in the form of a net. Computer network is therefore a system of interconnected computers in order to share resources; such as files exchange, or electronic communications. This consists of a collection of computers, printers and other equipment that is connected together so that they can communicate with each other. However computers on the networks are vulnerable to intrusion due to network wider expansion and openness both wired and wireless. Wireless Ad hoc network are particularly vulnerable due to their features of openness, vibrant changing topology, supportive algorithms, non centralized monitoring and management point and lack of defense (Yongguang and Wenke, 2000). Wired networks used anomaly detection methods that is not applicable to wireless network environment (Yassine, Abdellah, Youssef and Mohamed, 2015), due to the fact that wired network traffic had a concentrated points where the IDS gather and inspect data for the network, which is not applicable to wireless network (Safiqul and AshiqurRahman, 2011). High growth rate of wireless networks compared with traditional wired network is replacing traditional wired networks gradually due to their unique architecture and features (Abdulsalam, Tarek and Elhadi, 2014). Two different kinds of detection technique are:

1. Anomaly based IDS: This observe behaviour that are different from customary standard practice. This make use of statistical modeling to model anomaly detection component that has its bases as a reference and compare with actual parameters generated by the system or network under test (Vishwa & Salvatore, 2018 and Aljawarneha, Aldwairia & Yasina, 2017). It has high rate of false positive, it requires not previous knowledge of intrusion to detect new intrusions, as such it may not be able to illustrate the attack.

2. Signature based IDS: This makes used of blueprint of known attacks or a particular system weak spots to match and identify known intrusions. it is accurate and efficient in identify known attacks but inability to detect innovative (new) attacks (Safiqul et al, 2011).

### *2.3. Intrusion Detection and prevention System IDPS*

IDPS is a set of actions that identify and reports abnormality activities such as violation of privacy, reliability and network or computer accessibility (Safiqul et al, 2011). It inspects all inbound/outbound network operation and identifies any non adopted policy patterns from any system or individual on an attempt to break the lay down policy (Syed, Gabriel, Matt & Jeremy, 2016). Intrusion detection and prevention systems (IDPS) are mainly alert on identifying possible incidents, logging information concerning the incidents and reporting intrusion attempts. Intrusion detection and prevention systems (IDPS) technologies are differentiated by the types of proceedings that they monitor and the deployed conduct: Network based Intrusion Detection and prevention System (NIDPS) this analyzes the incoming and outgoing packets through the interface. It runs at the gateway of a network, captures and examines network packets that go through the network hardware interface. And host based Intrusion Detection and Prevention System (HIDPS): analyzes the incoming and outgoing packets through the interface gateway of a host. It captures and examines host packets that go through the system interface.

Numbers of research works have investigated the challenges of intrusion detection and prevention system. Where most of their suggested solutions deal with either detection or prevention of basic single host base malicious detection and or prevention and basically dynamic IP address. Nadiammai et al. (2014) suggested the concept of data mining integrated with an IDS to identify hidden relevant data, for effective packet classification using EDADT algorithm, Hybrid IDS model, Semi-Supervised Approach and Varying HOPERAA Algorithm. Alex et al. (2018) suggested artificial neural network (ANN) architecture that give an average accuracy of 98%, and an average rate of less than 2% of false positive. Aljawarneha et al. (2017) proposed an Anomaly-based hybridized intrusion detection approach that consists of J48, Meta Pagging, RandomTree, REPTree, AdaBoostM1, DecisionStump and NaiveBayes classifiers to give an improved accurate result.

Shamshirband et al. (2014) introduced cooperative-based fuzzy artificial immune system (Co-FAIS) where network agents work with one another to discover sensor's abnormality of in terms of context antigen value (CAV) to update fuzzy activation threshold for security response. To reinforced to defend against an incoming DDoS attack. Vishwa et al. (2018) come up with a wireless Sensor Network (WSN) security. Using an immune theory technique, designed based on the functions of various immune cells using energy, volume and frequency of data transfer as a basis for IDS design in WSNs to predicted different forms of attack for accurate detection of WSN attacks. Gupta, Dhawale & Misra (2016) called for dimensional security remedies to overcome challenges of insecurity in today's mobile communication system. They suggested lowest cluster identity and highest connectivity within the nodes as the cluster head and did distance based parameter cluster head selection to gives efficient way for detecting the malicious node.

## 3. Proposed Algorithm and Implementations

### *3.1. Methodology*

This paper presents a Host based Intrusion Detection and Prevention (HIDP) Security System for an organizational security control, as an additional support to Network based Intrusion Detection and Prevention System (NIDPS), to further strengthen the organisation security measure. It enforced combinations of User ID, User type, system MAC Address and assigned static IP address (USER ID + USERTYPE + MAC ADDRESS + IP ADDRESS) from network users, at Host level as Host based Intrusion Detection and prevention system (HIDPS). In order to gain access to an organisational system or network. Before an access can be granted/ permitted in an organizational network system.

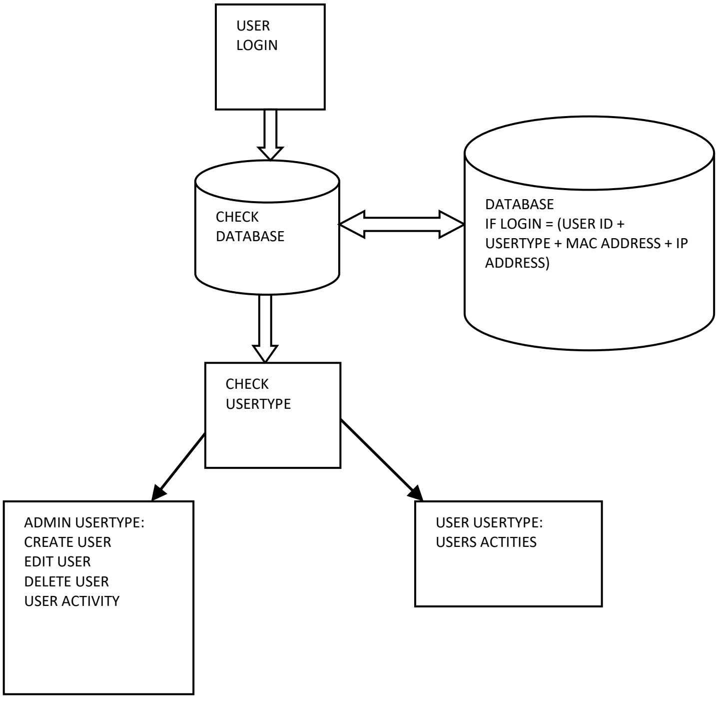



**Figure1:** Hybridized Intrusion Detection and Prevention System Using Static IP Address, Field Work

Security algorithm in figure 1 at the point of login compulsorily demand from user to supply the following login parameters: User ID, User type, system MAC address and assigned static IP address (USER ID + USERTYPE + MAC ADDRESS + IP ADDRESS). It then compare supplied parameters against the user supplied information at the point of registration stored in the database. if matched, user will be granted access, level of access granted user will be determined based on the user type. If ordinary user the level of access granted will be minimal, then further network security level will be implemented. But if user type is Administrator, user will be granted maximum access to operate on the system, before facing advanced level of network security. Otherwise, if user supplied wrong information, access is denied. Algorithm ensure total compliance of requested information from the user, before granting access to the legitimate users alone.

## 4. Results and Discussion

### *4.1. Results*

This show result of implementation of Algorithm in figure 1.

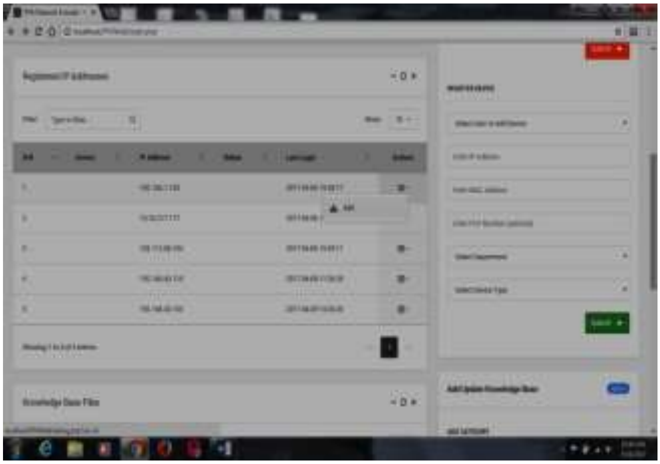


Figure 2: Registered IP Address Interface

This is an interface figure 2 where administrator register users, by assigning user with login information such as (User ID, User type, system MAC Address and assigned static IP address) that are compulsorily needed to login to the system or network.

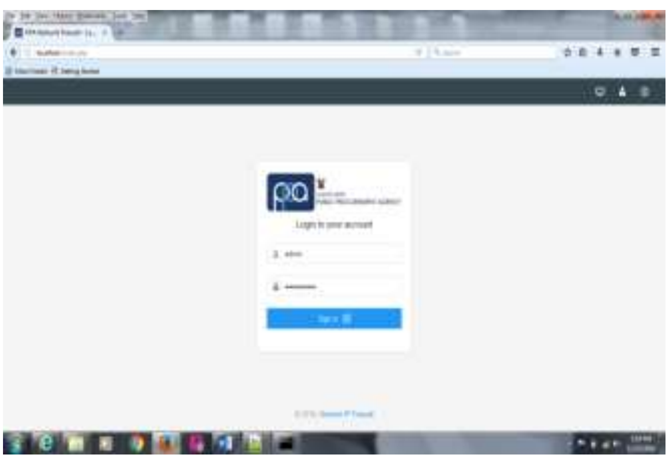


Figure 3: Login Interface

This is login interface figure 3 where user supply the login parameter in order to gain access to the system or network.

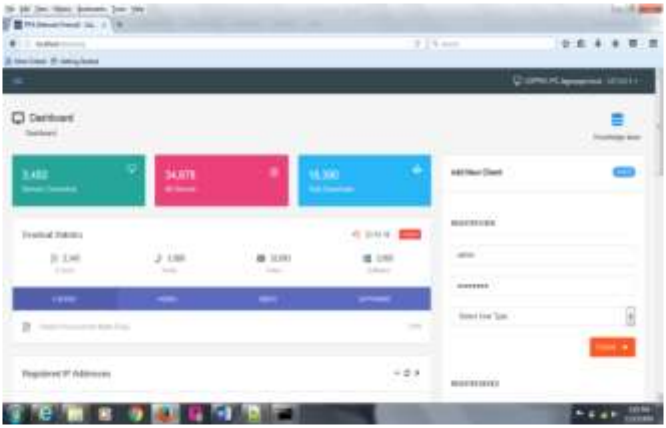


Figure 4: Dashboard Interface

Figure 4 is a dashboard interface, it is home page for users to supply their correct login parameters. To login to the system and then network to perform available choices of operation. User type (such as: user and administrator). control and determine level of operation a user can perform. The checking at this level is the initial level of security that further required other additional levels of security checking to ensure effective user /security affirmation.

### *4.2. Discussion*

Hybridized Intrusion Detection and Prevention System Using Static IP Address is highly effective at preventing unauthorized access to a system or network. At point of user login interface, to ensure user legitimacy before granting access. Result of the tested algorithm show that algorithm prevent access to user without correct required information supplied (such as correct: User ID, User type, system MAC Address and assigned static IP address) access denied is replied instead, at the host level. This prevent user from qualify for further level of network based security control. Both host and network based security levels are rigorously checked to guarantee system and network security safety against intrusion.

Hybridized based security system advantages cannot be over-emphasized in these modern days technology breakthroughs. Addition of a host based hybridized intrusion detection and prevention system, ensure system and network security reliability, to enforce minimal false positive and negative alert.

## 5. Conclusion

This algorithm strictly enforced supplying of all mandatory required login parameters (User ID, User type, system MAC address and assigned static IP address) before granting access to users, otherwise access is being denied. If any of the require information is missing or not properly supplied. The algorithm was tested and function efficiently and effectively accordingly. This served as an additional security measure for intrusion detection and prevention system.

## References

Abdulsalam, B., Tarek, S. and Elhadi, S. (2014). Implementation of A3ACKs intrusion detection system under various mobility speeds. 5th International Conference on Ambient Systems, Networks and Technologies. www.sciencedirect.com

Alex, S., David, D. and Aladdin, A. (2018). Intelligent intrusion detection systems using artificial neural networks. ICT Express 4. Pp. 95–99. www.elsevier.com/locate/icte

Aljawarneha, S., Aldwairia, M. and Yasina, M. B. (2017). Anomaly-based intrusion detection system through feature selection analysis and building hybrid efficient model. Journal of Computational Science. www.elsevier.com

Ananthi, P. and Balasubramanie, P. (2014). An Adaptive Hybrid Multi-level Intelligent Intrusion Detection System for Network Security. Research Journal of Applied Sciences, Engineering and Technology 7(16)

Ismail, B., Salvatore, D. M. and Ravi, S. (2013). A Survey of Intrusion Detection Systems in Wireless Sensor Networks. IEEE Communications Surveys & Tutorials. www.researchgate.net

Dave, S., Trivedi, B. and Mahadevia, J. (2013). Efficacy of Attack Detection Capability of IDPS Based On Its Deployment in Wired and Wireless Environment. International Journal of Network Security & Its Applications (IJNSA), Vol.5(2)

Debar, H., Dacier, M. and Wespi, A. (1999). Towards a taxonomy of intrusion-detection systems. Computer Networks. vol. 31, pp. 805-822.

Gupta, D., Dhawale, C. and Misra, S. (2016). A Cooperative approach for Malicious Node Detection in impromptu Wireless Networks.International Conference on Computational Techniques in Information and Communication Technologies (ICCTICT). IEEE

Han, Z. and Wang, R. (2012). Intrusion Detection for Wireless Sensor Network Based on Traffic Prediction Model, International Conference on Solid State Devices and Materials Science. Published by Elsevier

Heba, F. E., Ashraf, D., Abouland, E. H. and Ajith, A. (2018). Principle Components Analysis and Support Vector Machine based Intrusion Detection System 10th International Conference on Intelligent Systems Design and Applications. IEEE. Pp 363-367

Jabez, J. and Muthukumar, B. (2015).Intrusion Detection System (IDS): Anomaly Detection using Outlier Detection Approach. International Conference on Intelligent Computing, Communication & Convergence. Procedia Computer Science Vol. 48, pp. 338 – 346. www.sciencedirect.com

Jabez, J. and Muthukumar, B. (2014). Intrusion Detection System: Time Probability Method and Hyperbolic Hopfield Neural Network. Journal of Theoretical and Applied Information Technology. 67(1), pp 65-77.

Manikopoulos, C. and Papavassiliou, S. (2002). Network intrusion and fault detection: A statistical anomaly approach. IEEE Communications Magazine. 40(10), pp. 76–82.

Manu, B. (2016). A Survey on Secure Network: Intrusion Detection & Prevention Approaches. American Journal of Information Systems, Vol. 4(3). http://pubs.sciepub.com/ajis/4/3/2. Science and Education Publishing

Mehrnaz, M., Babak, S. and Iraj, M. (2018). Anomaly network-based intrusion detection system using a reliable hybrid artificial bee colony and AdaBoost algorithms. Journal of King Saud University –Computer and Information Sciences. www.sciencedirect.com.

Muamer, N. M. and Norrozila, S. (2012). Intrusion Detection System Based on SVM for WLAN Published by Elsevier Ltd. Procedia Technology Vol. 1, pp. 313 – 317. www.sciencedirect.com

Nadiammai, G.V. and Hemalatha, M. (2014). Effective approach toward Intrusion Detection System using data mining techniques. 15, pp. 37-50 www.elsevier.com/locate/eij, www.sciencedirect.com

Okunade, O. A. (2014). Multi-Level Based Hybridized Intrusion Detection and Prevention System. IOSR Journal of Computer Engineering (IOSR-JCE) 16(4), pp. 99-101 www.iosrjournals.org www.iosrjournals.org.

Osanaiye, O., Cai, H., Choo, K. R., Dehghantanha, A., Xu, Z. and Dlodlo, M. (2016). Ensemble-Based Multi-Filter Feature Selection Method for DDoS Detection in Cloud Computing. EURASIP Journal on Wireless Communications & Networking. Pp1-10

Paulo, A. C. and Joel, J. P. (2010). Internet Protocol over Wireless Sensor Networks, from Myth to Reality. Journal of Communications, 5(3), pp. 189-196

Rajendran, P. K, Muthukumar, B. and Nagarajan, G. (2015). Hybrid Intrusion Detection System for Private Cloud: A Systematic Approach. International Conference on Intelligent Computing, Communication & Convergence. Pp. 325 – 329. www.sciencedirect.com

Safiqul, I. M. and AshiqurRahman, S. (2011). Anomaly Intrusion Detection System in Wireless Sensor Networks: Security Threats and Existing Approaches. International Journal of Advanced Science and Technology (36)

Sandeep, K. S., Nishant, C. and Pragya, S. (2013). Concept and Proposed Architecture of Hybrid Intrusion Detection System using Data Mining, International Journal of Engineering and Advanced Technology (IJEAT). 2(5).

Shamshirband, S, Anuar, N.B., Kiah, M.L.M., Rohani, V. A., Petković, D., Misra, S. and Khan, A. N. (2014). Cooperative Fuzzy Artificial Immune System for Detecting Intrusion in Wireless Sensor Networks. Journal of Network and Computer Applications (Elsevier), 2014, Vol. 42, pp. 102–117. www.elsevier.com

Shaik, A., Rao, K. N. and Chandulal, J. A. ( 2010). Intrusion Detection System Methodologies

Based on DataAnalysis, International Journal of Computer Applications. 5(2), pp.10-20

Sonali, N., Madhuri A. D., Jyoti, B., Sunanyna S., Patil, D.Y. (2017). A Comparative Study of

Intrusion Detection System tools and Techniques. International Journal of Innovative Research in Computer and Communication Engineering. 5(8). www.ijircce.com

Srilatha, C., Ajith, A. and Johnson, P. T. (2004). Feature deduction and ensemble design of intrusion detection systems. Elsevier, Computers & Security. www.elsevier.com

Syed, R., Gabriel,L., Matt, G. and Jeremy, S. (2016). Advocating for Hybrid Intrusion Detection Prevention System and Framework Improvement. Published by Elsevier B.V. Procedia Computer Science Vol. 95, pp. 369 – 374. www.sciencedirect.com

Vani, A. H. (2016). Intrusion Detection: A Survey. International Journal of Innovative Research in Computerand Communication Engineering. Vol. 4(2). www.ijircce.com

Yassine, M., Abdellah, E., Youssef, Q. and Mohamed, M. (2015). A Global Hybrid Intrusion Detection System for Wireless Sensor Networks. The 5th International Symposium on Frontiers in Ambient and Mobile Systems. Published by Elsevier B.V. Computer Science 52, pp. 1047 – 1052. www.sciencedirect.com.

Vishwa, T. A, and Salvatore, D. M. (2018). A Multi-Level Intrusion Detection System for Wireless Sensor Networks based on Immune Theory. IEEE

Yongguang, Z. and Wenke, L. (2000). Intrusion Detection in Wireless Ad-Hoc Networks, Proceedings of the Sixth Annual International Conference on Mobile Computing and Networking. pp.6–11

*Covenant Journal of Informatics & Communication Technology. Vol. 7 No. 1, June, 2019*

**ISSN: p2354-3566 e 2354-3507 DOI: 10.20370/jfca-9t59**

*An Open Access Journal Available Online*

# A Review of Cluster Head Selection Schemes in Wireless Sensor Network for Energy Efficient Routing Protocol

**Ibrahim Rahman, Tekanyi A.M.S. & Abu-Bilal Kabir Ahmad**

Department of Communications Engineering
Faculty of EngineeringAhmadu Bello University, Zaria, Nigeria.
. ib.rahman26@gmail.com, amtekanyi@abu.edu.ng, kb.ahmad74@gmail.com

**Received: 9 06.2018 Accepted: 15.01.2019 Date of Publication: June, 2019**

***Abstract***— Energy management in Wireless Sensor Network (WSN) has attracted much concern due to the fact that the sensors are battery powered, and are usually deployed in hostile and inaccessible environments. With data transmission being the most energy consuming process in the network, several routing protocols based on clustering have been developed for energy efficient data transmission. The challenge of the clustering process in these protocols is the selection of Cluster Heads (CHs). This is due to the use of resource blind random generated number, high cost of network overhead, non-consideration of nodes' residual energy, and/or location to ensure even distribution of CHs. This paper reviewed energy efficient cluster based routing protocols for WSN and proposed better approaches to mitigate these problems in order to improve network stability and lifetime.

***Keywords/Index Terms***— WSN, CH, Clustering, Energy efficiency, Network lifetime.

## 1. Introduction

With advancements in Micro Electromechanical Systems (MEMS), development of small sized, low powered and low-cost sensor nodes is now more than possible. A network of large number of these nodes over wireless link constitutes a Wireless Sensor Network (WSN) (Mahboub et al., 2016). This is depicted in Figure 1.

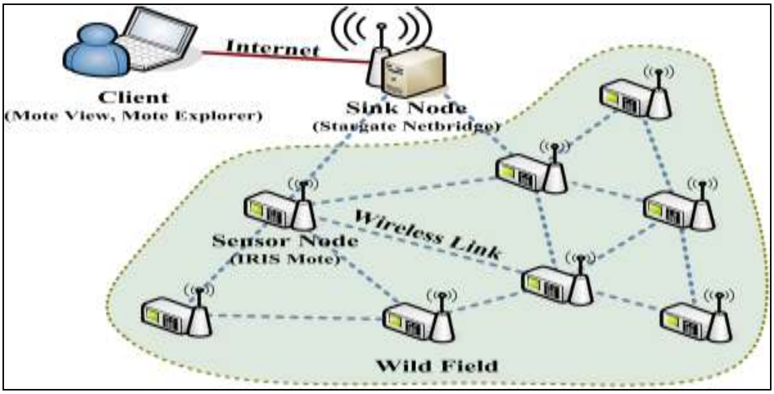


Figure 1: Wireless Sensor Network (Ma et al., 2016)

The sensor nodes collect physical information from the environment such as temperature, motion, and humidity to mention a few, process, and send it to the sink node, commonly referred to as a Base Station (BS). The BS further processes and makes the sensed information available to an end user.

Though motivated by military application such as battle field surveillance (Raghunandan et al., 2017), the WSN also finds application in civilian environment such as home automation (smart home), traffic control, industrial automation, and are in most cases, deployed in remote and hostile areas (Singh & Kumar, 2013).

Sensor nodes in WSN are usually battery powered, and due to the hostile nature of the area of deployment and the large number of nodes in the network, battery recharge or replacement is usually not feasible (Monica et al., 2012). Hence, the efficient use of the limited energy of the WSN is of great importance in its design. To this end, lots of techniques had been developed by various researchers which includes the Clustering technique. This groups the sensor nodes into clusters and electing for each, a Cluster Head (CH) which locally coordinates its cluster members in order to effectively utilizes the network limited energy. But still, the high cost of network overhead in selecting the CH remains an issue.

This paper reviews various clustering based techniques by researchers to improve the efficient use of the limited energy supply of the WSN, highlighting their limitations and suggests possible solutions that may be starting point for further research.

## 2. Basic Units of a Sensor Node

A typical sensor node consists of the following sub-components:

i. **Sensing unit**: this deals with sensing of the surrounding for desired information such as temperature, humidity, movement, etc. A node may have multiple sensor for sensing several information. The sensing unit consists of two subunits: sensor and Analog to Digital Converters (ADC). The ADC converts the analog signals collected by the sensor to its digital form.

ii. **Processing unit**: this unit preprocess the sensed information before transmission. It usually consists of a microcontroller or microprocessor with memory and provides intelligent controls to the sensor node.

iii. **Communication/ Transceiver/ Radio unit**: this unit is responsible for data transmission and reception.

iv. **Power unit**: this provides the power needed for the functioning of the various sub-components of the sensor.

Figure 2 shows the energy consumption of these sub-components and indicates that, the communication sub-component of a sensor node consumes the most of the energy supply of the sensor node. Hence, an energy efficient communication protocol is a necessity in the design of a WSN to efficiently utilize its limited energy and improve the network lifetime.

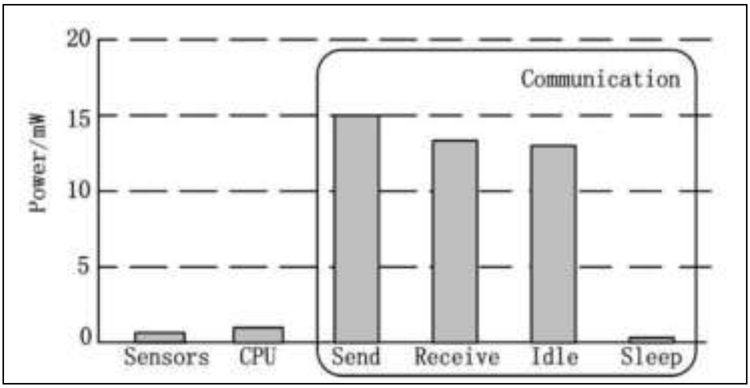



*Figure 1: Energy Consumption of the sub-components of a Senor Node (Yan* et al., *2016)*

The clustering technique is a method of decreasing energy consumption and increasing network lifetime (Ablolfazl et al., 2015). This groups the sensor nodes into clusters with each been supervised by a node elected as the Cluster Head (CH). The CH collects sensed data from its cluster members, aggregates and sends it to the BS. This technique usually consists of two phases: the setup and steady state phases (Jan et al., 2013). During the setup phase, CHs are elected and clusters are formed while data transmission occurs during the steady state phase. Both the setup and steady state phases constitute a round.

## 3. Classification of Cluster Based Routing Protocol

Clustering routing protocol can either be a distributed routing protocol or a centralized routing protocol, depending on the manner of CH selection and cluster formation (Jan et al., 2013).

### 3.1 Distributed Routing Protocol

Also known as self-organizing routing protocol, sensor nodes are designed with enough intelligence to autonomously organize themselves into clusters and elect CHs without the assistance of an external agent. A global knowledge of the network is not needed during operation and hence the network does not experience delay and waste of limited network energy resulting from acquiring global network knowledge. But then, this protocol does not guarantee the number of CHs in the network and may result to the election of non-optimal number of CHs for energy efficient routing in the network.

### 3.2 Centralized Routing Protocol

In this protocol, an external agent (usually the BS) assists the sensor nodes, partially or fully, to organize them into clusters and election of CHs, hence it is sometimes referred to as BS assisted routing protocol. The BS serves as a central coordinator of the nodes and requires updates from the sensor nodes to have a global network knowledge. Unlike the distributed routing protocol, the centralized routing protocol does guarantee the number of CHs but does experience delay and use of considerable network energy for updating network status to the BS.

## 4. Low Energy Adaptive Clustering Hierarchy

The Low Energy Adaptive Clustering Hierarchy (LEACH) is a pioneer clustering routing protocol for WSN (Heinzelman et al., 2000). It balanced energy load among nodes by rotating the role of CH among them thereby improving the network lifetime. CHs in this protocol were probabilistically selected using a threshold given by equation 1.

$$T = \begin{cases} \frac{p}{1-p\left(r\, mod \frac{1}{p}\right)} & if\ n \in G \\ 0 & otherwise \end{cases} \qquad (1)$$

where:

p is the percentage of total nodes required as CH for energy efficient routing

r is the current round

G is the set of node that haven't been elected as CH in the last $\frac{1}{p}$ rounds

In Heinzelman et al., (2002), an analytical approach is given to determine the optimal value of the percentage (p) of the total deployed nodes required as CHs for energy efficient routing.

In becoming a CH, each node generates a random number between zero, and one and compares it with the threshold. All nodes having a number less than the threshold are elected as CHs for the current round. This protocol had gone through several modifications due to some limitations. Most significant is the non-consideration on nodes energy in CHs selection which rise to low energy becoming a CH in the presence of high energy nodes.

## 5. Review of Energy Efficient CH Selection Schemes

In Barfunga et al., (2013), a cluster based energy efficient routing protocol was proposed to improve network life time. In this protocol, the BS was tasked with the responsibility of CH selection based on the node energy, location, node degree (number of a node's neighbours), and number of times it had previously been elected as CH. Based on the afore-mentioned parameters, in each round, a list of ten tentative CH nodes was created. Starting with the best candidate at the top, with priority given to the node having lesser values of distance to the BS and number of times it had previously been elected to serve as CH, and higher values of residual energy and node degree. Five of these tentative CHs were selected as the final CHs based on the physical distance between the nodes to ensure an even distribution of CH. This protocol assumed that the BS could discover the relative position of the nodes and topology of the network in current time and showed an improvement over LEACH in terms of network lifetime. In order to elect CHs in subsequent rounds, the BS required an update of nodes' residual energy which consumed the limited network energy supply leading to a short network stability and lifetime.

Jan et al., (2013) carried out a modification of the LEACH protocol cluster head selection threshold by considering the energy consumption of the nodes. This showed an improvement in network stability and lifetime. However, in the first round where the energy consumption of the nodes was zero, the threshold evaluated to zero and as such no CH was elected in the first round. Also, after the first round in the early stage of the network, the energy consumed by each node was still very low (almost zero). This resulted to a threshold value which was almost zero and became impossible for a node to generate a random number less than the threshold. Hence, no CH was formed.

Mahmood et al., (2013) introduced a modified LEACH (MODLEACH). This protocol introduced an energy efficient CH replacement scheme and a dual transmitting power levels to improve the network throughput and lifetime. A CH once elected, operated for some rounds until its energy fall below a certain threshold before a new selection process was initiated according to LEACH protocol. This was to reduce overhead for clustering in every round. Also, nodes used different power levels for transmitter amplifier in intra and inter cluster communication with inter cluster communication having the highest. However, nodes in the protocol had to put their receiver in idle state in order to be able to determine when a new cluster head selection process was initiated. This consumed network energy and reduced the lifetime of the network.

Nayak et al., (2014) presented a novel cluster head selection method for energy efficient wireless sensor network. In this work, the sensor field was partitioned into regions of diminishing size away from the BS with each region further divided into clusters which remained so throughout the network lifetime. This ensured that clusters were reduced in size with distance away from the BS. Hence, larger cluster spent more energy for intra-cluster communication and less for CH to BS communication since it has more cluster members and close to the BS. Also, smaller cluster spent less energy for intra-cluster communication and more for CH to BS communication since it had less cluster member and was farther away from the BS. This formed a trade-off between the cluster size and distance to BS. The selection of CH was dependent on the nodes residual energies, average distance to neighbouring nodes and distance to the BS. The BS computed a CHfactor for each node in a cluster and elected the node having the highest CHfactor as CH for the current round. This protocol showed an improvement in terms of energy consumption and network lifetime as compared to LEACH. However, it required nodes to send their energy status to the BS in every round for subsequent election of CHs. This required significant network energy and resulted to a short network lifetime.

Eshaftri et al., (2015) presented a load-balancing cluster-based protocol. In this protocol, once clusters were formed, load was balanced between the sensor nodes by rotating the role of CH among themselves for a number of rounds before re-clustering. At the beginning of network deployment, every node exchanged their information with their neighbour (in order to compute its cost) and then established its probability of becoming a CH. Based on this probability, each could be a CH or tentative-CH. The final CH broadcast its statue within its range and every other member joined the closest CH. Node which was neither CH and had not received any broadcast declared itself as a CH. Each CH then constructed a turn-table for its CM based on their residual energy. The CH in the next round will be the node having the highest residual energy. Hence it is not necessary that re-clustering takes place in every round. Once the first cluster finished the rotating process, it sent a re-cluster message to the BS which was broadcasted to every node to start a new cluster process. Compared to LEACH, this protocol achieved an improvement on the network lifetime. However, every node dissipated much energy in updating its residual energy to the CH and it could also lead to large number of CH when a large number of node do not receive the broadcast sent by CHs and then declared themselves as CH. Also, it required nodes to put their receiver in idle state in order to know when a re-cluster message was sent by the BS. This resulted to a wasteful use of energy.

Gwavava et al., (2015) proposed, yet another LEACH (YA-LEACH) which introduced a vice-CH in each cluster. A node maintained the role of a CH for several rounds (to reduce control messages in cluster formation) until its energy fell below a certain threshold and then it transferred its role as CH and current data to the vice-CH (to avoid data loss) which became the CH till the next cluster formation. This protocol used a centralized approach for cluster formation, determined based on the network information gotten directly from the nodes. In subsequent cluster formation, nodes sent their status through their corresponding CH. Also, the selection of CHs was dependent on their residual energy and location while the vice-CH are selected based on minimum distance from the CH and having the maximum residual energy for the role. This protocol achieved an improved network life time when compared with LEACH but however a reduced stability of the network which was attributed to the extended CH round of operation and hence dissipate energy much faster.

Prince et al., (2016) presented work to solve hot spot problem in a multi-hop cluster based routing protocol by load balancing using clusters of unequal sizes, thereby improving network lifetime and stability. The BS divided the sensor field into fixed rectangular clusters of unequal sizes which depended on their distance from the BS. Clusters closest to the BS were smallest in size (having a fix width but a variable length) while those farther away were greatest in size, having a length not greater than the threshold distance $(d_o)$ of the radio model. This ensured that the inter-hop distance is restricted to ensure free space propagation model at all time. For each cluster, the node having residual energy greater than its cluster average energy and closest to the centroid of the cluster was elected as CH. This protocol also introduced mobile Data Mule (having no power issue) to collect data from the gateway CH (CH closest to the BS) and also gave an improved energy efficiency than existing protocols but due to fixed clustering, some nodes expended more energy communicating with their CH in the presence of closer CHs from neighbouring clusters.

Ellatief et al., (2016) proposed an energy-efficient density-based clustering technique to balance the energy consumption among clusters by the adaptation of transmission range of CH with respect to the node density by defining a set of nodes that borders the sub-regions (clusters) using a border detection technique. This designated nodes as border or interior nodes. CHs in this protocol were elected based on the node degree and level. The technique did not consider the energy of the node implying that a node with a low residual energy could be assigned the role of a CH.

Singh & Verma, (2017) proposed energy efficient cross layer based adaptive threshold routing protocol for WSN. CHs in this approach were selected based on a weighted factor which was depended on the mean energy of the network and node residual energy. Every node generated a random number which was compared with the weighted factor. Those having a number less than the factor were selected as CHs. The network comprised of heterogeneous nodes having three different energy levels classified as super-advanced node, advanced node, and normal node. This protocol showed an improvement in the network lifetime and stability period but the CHs selection was based on a generated random number which is resource blind. Hence, low energy node could become a CH in the presence of a high energy node leading to a short network stability and lifetime.

Ma et al., (2016) proposed a centralized clustering formation using the BS partially for the CH selection process. Though this protocol used a randomly generated number to select CH, it eliminated the chance of a node with low residual energy to become a CH. This was achieved with the help of the BS which selected a set of nodes based on their energy that were through the CH selection process. These were nodes whose residual energy was greater than the average network energy by a multiple (determined through simulation) of the energy consumption per round. If this set of nodes were less than the optimal number of CH, the set was reelected by considering nodes with residual energy greater than average network energy. This protocol showed an improvement in energy efficiency and prolonged network survival time. Its limitation was that it required a high cost of control packets in transmitting nodes energy statue to the BS in every round. Also, the location of these nodes is not considered in CHs selection. This did not allow an even distribution of the CHs, resulting in the high cost of intra cluster communication.

Elshrkawey et al., (2018) presented An Enhancement Approach for Reducing the Energy Consumption in Wireless Sensor Networks by taking into consideration the residual energy and initial energies of nodes, average network energy, distance of CHs to BS and the distance of nodes to CH to reduce the chances of low energy nodes becoming a CH. This improved the network lifetime but still, is limited by the use of resource blind randomly generated number which still result to low energy nodes becoming a CH and also the number of CH is usually above the required for energy efficiency.

Jesudurai & Senthilkumar, (2018) proposed an improved energy efficient cluster selection technique in LEACH to improve the throughput and network lifetime. By selecting two CHs for each cluster then decrease the consumption of energy. However, this still retained the limitations of the LEACH protocol as it does not consider the energy of the nodes in the selection processes.

Zahedi, A. (2017) improved the network lifetime of LEACH by taking into consideration residual energy of each node, distance to sink and applying weighting coefficients in the selection of CHs. However, this could not ensure the selection of an optimal number of CHs for energy efficiency as there is no central coordination of the selection process.

| S/N | AUTHOR (YEAR) | NETWORK TYPE AND PARAMENTS USED | ACHIEVEMENT | LIMITATION | ENERGY EFFICIENCY | CLUSTER STABILITY |
|---|---|---|---|---|---|---|
| 1. | Barfunga *et al.,* (2013) | Centralized network. Uses: 1. node residual energy 2. location 3. number of neighbours 4. number | Improved network lifetime as compared to LEACH. | Updates required for CH selection resulted in high network overhead. | Medium | Medium |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | of times previously elected as CH. | | | | |
| 2. | Jan *et al.,* (2013) | Distributed network.<br>1. percentage of required CH<br>2. consumed energy<br>3. number of times previously elected as CH. | Improved network stability and lifetime as compared to LEACH. | Difficulty in electing CH at network deployment due to zero initial consumed up energy. | Medium | Medium |
| 3. | Mahmood *et al.,* (2013) | Distributed network.<br>1. percentage of required CH<br>2. number of times previously elected as CH. | Reduced network overheads in CH selection hence improving network lifetime. | Idle state of receivers consumed significant amount of energy. | High | Low |
| 4. | Nayak *et al.,* (2014) | Distributed network.<br>1. residual energies<br>2. average distance to neighbours<br>3. distance to the BS | Improved network lifetime as compared to LEACH. | Updates required for CH selection resulted in high network overhead. | Medium | Medum |
| 5. | Eshaftri *et al.,* (2015) | Centralized network.<br>1. Residual energy<br>2. location | Improved network lifetime as compared to LEACH. | Updates required for CH selection resulted in high network overhead.<br><br>Idle state of receivers consumed significant amount of energy. | Medium | Medium |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | It could also lead high number of CH required for energy efficiency. | | |
| 6. | Gwavava *et al.*, (2015) | Centralized network.<br>1. residual energy<br>2. location<br>3. distance | Improved network lifetime compared to LEACH. | Reduced stability of the network due to the extended CH round of operation | High | Low |
| 7. | Prince *et al.*, (2016) | Distributed network<br>1. Energy<br>2. Location | Improved network lifetime and stability | Due to fixed clustering, some nodes use communicating with their CH in presence of a closer CH in neighbouring cluster | Medium | High |
| 8. | Singh & Verma, (2017) | Centralized network.<br>1. mean network energy<br>2. node residual energy<br>3. randomly generated number | Improved network lifetime and stability period. | Use of randomly generated number which is resource blind could to election of low energy nodes as CH. | High | High |
| 9. | Ma *et al.*, (2016) | Centralized network.<br>1. energy<br>2. percentage of required CH<br>3. randomly generated number. | Improve network stability and lifetime in LEACH. | High cost of control packets. Also, the non-consideration of location resulted to an uneven distribution on CH. | High | Medium |
| 10. | Elshrkawey *et al.*, (2017) | Distributed<br>1. residual energy<br>2. initial energies<br>3. average network energy, | Improved network lifetime in LEACH. | Chances of selecting a low energy node as CH and also the selection of sub-optimal number of CHs for energy efficiency. | High | High |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | distance of CHs to BS<br>4. the distance of nodes to CH | | | | |
| 11. | Jesudurai & Senthilkumar, (2018) | Distributed network.<br>1. percentage of required CH<br>2. number of times previously elected as CH. | Improved throughput and network lifetime in LEACH. | non-consideration of energy in the selection processes | High | High |
| 12.` | Zahedi, A. (2017) | Distributed network.<br>1. percentage of required CH<br>2. residual energy of nodes<br>3. number of times previously elected as CH.<br>4. Distance to sink<br>5. Weighted coefficient | Improved network lifetime compared to LEACH. | Selection of sub-optimal number of CHs for energy efficiency. | Medium | Medium |

## 6. Conclusion

This paper discusses the types of cluster based energy efficient routing protocol in WSN. The major difference between the various clustering protocols is in the clustering method with a focus on the CH selection. The aim is to select nodes with high residual energy as CHs in order to avoid nodes from running out of energy quickly thus extending the network stability and lifetime. For better performance of WSN in terms of network stability and lifetime, the following recommendations are suggested:

- **i.** The development of a new routing protocol should focus on improving the existing cluster based routing protocols in WSN by optimizing the control messages required in clustering and CH selection
- **ii.** Pre-selection of current and future tentative CHs at network deployment in order to avoid nodes from sending updates for each re-clustering and CHs selection.

**iii.** Metaheuristic and heuristic optimization tools such as Artificial Fish Swamp Algorithm (AFSA) and Knapsack Algorithm can be tested in modeling the clustering process in WSN while considering nodes energy distribution and the distribution of CHs in the sensor field.

## References

Mahboub, A., Arioua, M., & Ez-Zazi, I. (May, 2016). Multiple zonal approach for clustered wireless sensor networks. *In Electrical and Information Technologies (ICEIT), 2016 International Conference*. IEEE. 219-224.

Singh V.P. & Kumar H. (July, 2013). Base Station Assisted Routing Protocol for Wireless Sensor Network. International Journal of Engineering Research & Technology (IJERT). (2)7, 530 – 536.

Monica R., Savan K., Shivanand K., Raja N. & Seira A. (2012). A study on energy efficient routing protocols in wireless sensor networks. *International Journal of Distributed and Parallel Systems (IJDPS)*, 3(3), 311-330.

Heinzelman W. B., Chandrakasan A. P. and Balakrishnan H. (2002) "An application-specific protocol architecture for wireless microsensor networks," IEEE Transaction Wireless Communications. 1(4), 1-7.

W.R. Heinzelman, A. Chandrakasan and H. Balakrishna, (2000). Energy-efficient communication protocol for wireless microsensor networks. *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences*. 2, 1-10.

Yan, J., Zhou, M., & Ding, Z. (2016). Recent Advances in Energy-Efficient Routing Protocols for Wireless Sensor Networks: A Review. *IEEE Access*, 4, 5673-5686.

Ablolfazl A. K., Hamed J. and Javad A. (2015). LEACH and HEED clustering algorithms in wireless sensor network: *A qualitative study. Advances in Science and Technology Research Journal*. 9(25), 7-11.

Jan, M. A., Nanda, P., He, X., & Liu, R. P. (Nov, 2013). Enhancing lifetime and quality of data in cluster-based hierarchical routing protocol for wireless sensor network. *In High Performance Computing and Communications & 2013 IEEE International Conference on Embedded and Ubiquitous Computing (HPCC_EUC), 2013 IEEE 10th International Conference. IEEE. 1400-1407*.

Barfunga, S. P., Rai, P., & Sarma, H. K. D. (2012, July). Energy efficient cluster based routing protocol for Wireless Sensor Networks. *In Computer and Communication Engineering (ICCCE), 2012 International Conference IEEE*. 603-607

Jan, M. A., Nanda, P., He, X., & Liu, R. P. (Nov, 2013). Enhancing lifetime and quality of data in cluster-based hierarchical routing protocol for wireless sensor network. *In High Performance Computing and Communications & 2013 IEEE International Conference on Embedded and Ubiquitous Computing (HPCC_EUC), 2013 IEEE 10th International Conference. IEEE. 1400-1407*.

Mahmood D., Javaid N., Mahmood S., Qureshi S., Memon A. M., & Zaman T. (October, 2013). MODLEACH: a variant of LEACH for WSNs. *In Broadband and Wireless Computing, Communication and Applications (BWCCA), 2013 Eighth International Conference*. IEEE. 158-163.

Nayak B. K., Mishra M., Rai S.C. & Pradhan S.K. (2014). A Novel Cluster Head Selection Method for Energy Efficient Wireless Sensor Network. *International Conference on Information Technology*. 53 – 57

Eshaftri, M., Al-Dubai, A. Y., Romdhani, I., & Yassien, M. B. (2015, September). A new energy efficient cluster based protocol for wireless sensor networks. *In Computer Science and Information Systems (FedCSIS), 2015 Federated Conference* IEEE. 1209-1214.

Gwavava, W. T., & Ramanaiah, O. B. V. (2015, December). YA-LEACH: Yet another LEACH for wireless sensor networks. *In Information Processing (ICIP), 2015 International Conference*. IEEE. 96-101.

Prince B., Kumar, P., Singh, M. P., & Singh, J. P. (2016, March). An energy efficient uneven grid clustering based routing protocol for Wireless Sensor Networks. *In Wireless Communications, Signal Processing and Networking (WiSPNET), International Conference*. IEEE. 1580-1584.

Ellatief, W. A., Younes, O., Ahmed, H., & Hadhoud, M. (2016, February). Energy efficient density-based clustering technique for wireless sensor network. *In 2016 8th International Conference on Knowledge and Smart Technology (KST)*. IEEE. 196-200

Singh, R., & Verma, A. K. (2017). Energy efficient cross layer based adaptive threshold routing protocol for WSN. *AEU-International Journal of Electronics and Communications*, 72, 166-173.

Ma, Z., Li, G., & Gong, Q. (2016). Improvement on LEACH-C Protocol of Wireless Sensor Network (LEACH-CC). *International Journal of Future Generation Communication and Networking*. 9(2), 183-192.

Raghunandan, G. H., Rani, A. S., Nanditha, S. Y., & Swathi, G. (2017, July). Hierarchical agglomerative clustering based routing algorithm for overall efficiency of wireless sensor network. In *Intelligent Computing, Instrumentation and Control Technologies (ICICICT), 2017 International Conference on* (pp. 1290-1293). IEEE.

Elshrkawey, M., Elsherif, S. M., & Wahed, M. E. (2018). An enhancement approach for reducing the energy consumption in wireless sensor networks. *Journal of King Saud University-Computer and Information Sciences*, 30(2), 259-267.

Jesudurai, S. A., & Senthilkumar, A. (2018). An Improved Energy Efficient Cluster Head Selection protocol using the double cluster heads and data fusion methods for IoT applications. *Cognitive Systems Research.*

Abdulhamid Zahedi (2017). An efficient clustering method using weighting coefficients in homogeneous wireless sensor networks. *Alexandria Engineering Journal*

Covenant Journal of Informatics & Communication Technology. Vol. 7 No. 1, June, 2019

ISSN: p2354-3566 e 2354-3507 DOI: 10.20370/yhas-n460

An Open Access Journal Available Online

# Graphical User Interface (GUI) for Position and Trajectory Tracking Control of the Ball and Plate System Using H-Infinity Controller

**Abubakar Umar[1]*, Zaharudden Haruna[1], Umar Musa[2], Shehu Aminu Mohammed[2], Momoh Omuya Muyideen[1]**

[1]Computer Engineering Department, Ahmadu Bello University, Zaria, Kaduna, Nigeria
[2]Electrical Engineering Department, Ahmadu Bello University, Zaria, Kaduna, Nigeria
abubakaru061010@gmail.com, elzet2007@gmail.com, umarnadada@yahoo.co.uk
amshehu12@gmail.com, momuyadeen@gmail.com
*Corresponding Author

**Received: 05. 02. 2019 Accepted: 16. 04. 2019 Date of Publication: June, 2019**

***Abstract***: In this paper, a graphical user interface (GUI) for position and trajectory tracking of the ball and plate system (BPS) control scheme using the double feedback loop structure i.e. a loop within a loop is proposed. The inner and the outer loop was designed using linear algebraic method by solving a set of Diophantine equations and sensitivity function. The results were simulated in MATLAB 2018a, and the trajectory tracking was displayed on a GUI, which showed that the plate was able to be stabilized at a time of 0.3546 seconds, and also the ball settled at 1.7087 seconds, when a sinusoidal circular reference trajectory of radius 0.4m with an angular frequency of 1.57rad/sec was applied to the BPS, the trajectory tracking error was 0.0095m. This shows that the controllers possess the following properties for the BPS, which are; good adaptability, strong robustness and a high control performance.

***Keywords***: Ball and plate system (BPS), controller, graphical user interface (GUI), linear algebraic method and Diophantine equation.

## 1. Introduction

Balancing is amongst the most difficult and interesting aspect in the field of control engineering. There are a lot of benchmark control systems for studying and testing of control algorithms that is used to balance the systems like; the ball and beam system (BBS), double inverted pendulum and the traditional cart-pole system (inverted pendulum) (Cheng & Tsai, 2016). The BPS is a benchmark nonlinear plant that is more complex than the BBS; which is amongst the most pertinent and integral models in control engineering education, and is used at undergraduate and post-graduate studies in teaching and testing of control algorithms (Galvan-Colmenares et al., 2014; Oravec & Jadlovská, 2015). The BPS, an extension of the BBS is a nonlinear and multivariable system (Bigharaz et al., 2013; Cheng & Chou, 2016), which consist of a ball that rolls freely on a flat horizontal plate. The ball is required to follow a given path by manipulating the plates tilt with respect to the two mutually perpendicular directions (Roy et al., 2016b). The control objective of the BPS is to balance and allow the ball to track the reference trajectory on the flat plate, by tilting the plate with respect to the horizontal plane. This BPS is very important to the control engineer, because it allows a user to study and validate different linear and nonlinear systems before applying it to real life problem that exhibits such similar dynamics (Debono & Bugeja, 2015). The BPS has four degrees of freedom (DOF), the tilt of the plate is controlled by two actuating inputs, which indicates that it is an under-actuated system (Das & Roy, 2017). It is an open-loop unstable system, as the balls position becomes uncontrolled when the plate is in a tilted position either on its x or y-axis (Farooq et al., 2013), this results in difficulty in modelling and control of the BPS (Roy et al., 2016a). The system can be applied in areas like unmanned aerial vehicle (UAV), humanoid robots, rocket systems and satellite control (Cherubini et al., 2009; Mukherjee et al., 2002) in the following fields like; friction compensation, trajectory tracking and path planning (Oriolo & Vendittelli, 2005).

Stabilization and trajectory tracking of the BPS has been investigated with the use of different control schemes, some research works has been done using classical controllers like in the work of (Yıldız & Gören-Sümer, 2017) and Dušek et al. (2017), which used the first principle and optimal control approach; the proportional-integral-differential (PID) controllers; Zeeshan et al. (2012) used PID controllers with a discrete phototransistor to design, control and implement the BPS. However, Mohammadi and Ryu (2018) used neural network to tune PID gains of the nonlinear BPS. Also, Aphiratsakun and Otaryan (2016) compared the tuning technique of PID controllers using MATLAB/Simulink with that of manual tuning technique that was on the basis of the trial and error process, and PID tuning methods from Ziegler-Nichols and Tyreus-luyben (closed-loop proportional gain control or P-Control test), and Ali and Aphiratsakun (2015) used PID controller to demonstrate how to make the ball balance on the plate. Others used PID controllers optimized by some meta-heuristic algorithms like Dong et al. (2009), applied genetic algorithm (GA) to on-line updated PID neural network controller for the BPS. However, Fei et al. (2011) tuned the

PID controller of the BPS using RBF neural network. The RBF neural network tuned PID controller of the system was compared with the conventional PID and fuzzy controller, Han et al. (2012) tuned the PID controller using an improved particle swarm optimization (PSO) on-line training of the PID neural network controller, also Bang and Lee (2018) implemented the BPS on a steward platform using sliding mode controller (SMC), and compared the result of the SMC with that of linear quadratic (LQ) control and experimental results. Other researchers have modified the PID controller to PD controllers tuned by other meta-heuristics (Borah et al., 2014; Roy et al., 2015). Others used I-PD (Mochizuki & Ichihara, 2013), in which the PID controller was designed based on the generalized Kalman-Yakubovich-Popov lemma, Galvan-Colmenares et al. (2014) modified the normal proportional-diffrential (PD) controller to a new dual form for the control of the BPS. Also, others used fuzzy logic controller (Fan et al., 2004; C. E. Lin et al., 2014; Ming et al., 2011), neural network controller (Singh & Bhushan, 2018; Wang et al., 2012), robust controllers like sliding mode controller (Morales et al., 2017; Suleiman et al., 2018), H-infinity controller (H.-Q. Lin et al., 2014; Umar et al., 2018) and linear quadratic Gaussian (LQG) controller (Jafari et al., 2012; Umar et al., 2019).

The most important control scheme of the BPS is the double feedback loop structure, which is a loop in a loop is adopted (Liu & Liang, 2010) in this research, also researchers have adopted the double feedback loop structure (Das & Roy, 2017; Negash & Singh, 2015; Roy et al., 2016a). The inner loop functions as a position controller that used DC servo motor, while the outer loop functions as a linear controller that controls the position of the ball (Liu & Liang, 2010).

In this paper, the BPS is viewed as a double feedback loop structure for position and trajectory tracking control. The inner feedback loop which is controlled by a DC motor servo controller for positioning of the ball on the plate will be designed using linear algebraic method in which a set of Diophantine equations will be solved, and the outer loop will also be designed using H-infinity controller. A MATLAB based graphical user interface (GUI) will be developed for the trajectory tracking of the BPS.

The paper is structures as follows; section 2 gives the mathematical modelling of the BPS, and section three elaborates on the materials and methods that was used for the design of the system. Section four discusses the simulation results of the double feedback loop structure of the BPS, finally the conclusion is given in section five.

## Mathematical Model of the BPS

The HUMUSOFT laboratory model of the BPS is shown in Figure 1.

Figure 1: The Humusoft BPS laboratory model (humusoft Ltd., 2012a)

Also, the mathematical schematic model of the BPS is given in Figure 2.

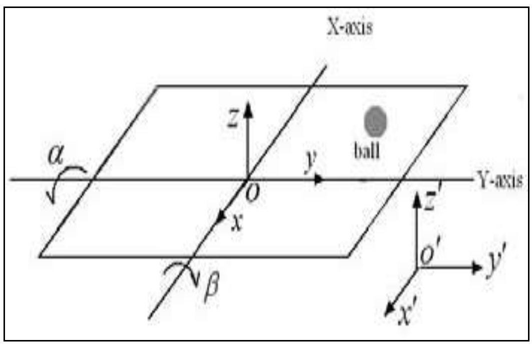



Figure 2: The schematic model for the BPS

The plate rotates in two different axis, which are x-and –y-axis, and are in perpendicular directions. The Kinematic differential equations of the BPS are derived by the use of Euler-Lagrange equation, which is written as (Escobar *et al.*, 2017; Kassem *et al.*, 2015):

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{q}_i} - \frac{\partial T}{\partial q_i} + \frac{\partial V}{\partial q_i} = Q_i \qquad (1)$$

$q_i$ represents the $i^{th}$ -direction coordinate, $T$ also represents the kinetic energy of the system, $V$ gives the potential energy, and $Q$ is the composite force.

The BPS can be represented in a simple form as a particle system that consist of two rigid bodies; the plate's geometry has limits in translation along the x-y-z axis, and also a geometry limit in rotation about the z-axis. The plate has two DOF in rotation about the x-y axis. The ball's geometry limit in translation is along the z-axis. It has two DOF along the x-y-axis. The BPS system model has four DOF, which has the generalized coordinates as (Hussein *et al*., 2017; Saud & Alwan, 2017):

$$q_1 = x,\ q_2 = y,\ q_3 = \alpha,\ q_4 = \beta$$

The total kinetic energy of the system is represented in equation (2):

$$T = T_{ball} + T_{plate} \tag{2}$$

$$T_{ball} = \frac{1}{2}\begin{bmatrix} \left(m_b + \frac{J_b}{R_b{}^2}\right)\left(\dot{x}^2 + \dot{y}^2\right) + J_b\left(\dot{\alpha}^2 + \dot{\beta}^2\right) \\ m_b\left(x\dot{\alpha} + y\dot{\beta}\right)^2 \end{bmatrix} \tag{3}$$

$$T_{plate} = \frac{1}{2}\begin{bmatrix} \left(J_{Px}\dot{\alpha}^2 + J_{py}\dot{\beta}^2\right) + \left(m_b + \frac{J_b}{R_b{}^2}\right)\left(\dot{x}^2 + \dot{y}^2\right) \\ + J_b\left(\dot{\alpha}^2 + \dot{\beta}^2\right) + m_b\left(x\dot{\alpha} + y\dot{\beta}\right)^2 \end{bmatrix} \tag{4}$$

The potential energies of the system along the x-y-axis is given as:

$$V_x = m_b g x \sin\alpha \tag{5}$$

$$V_y = m_b g y \sin\beta \tag{6}$$

The mathematical equation of the BPS is given as:

$$\left(m_b + \frac{J_b}{R_b{}^2}\right)\ddot{x} - m_b x\left(\dot{\alpha}\right)^2 - m_b y\dot{\alpha}\dot{\beta} + m_b g\sin\alpha = 0 \tag{7}$$

$$\left(m_b + \frac{J_b}{R_b{}^2}\right)\ddot{y} - m_b y\left(\dot{\beta}\right)^2 - m_b x\dot{\alpha}\dot{\beta} + m_b g\sin\alpha = 0 \tag{8}$$

$$\begin{aligned}\left(m_b x^2 + J_b + J_{Px}\right)\ddot{\alpha} + 2m_b x\dot{x}\dot{\alpha} + m_b xy\ddot{\beta} \\ + m_b\left(\dot{x}y + x\dot{y}\right)\dot{\beta} + m_b g x\cos\alpha = \tau_x\end{aligned} \tag{9}$$

$$\begin{aligned}\left(m_b y^2 + J_b + J_{Py}\right)\ddot{\beta} + 2m_b y\dot{y}\dot{\beta} + m_b xy\ddot{\alpha} \\ + m_b\left(\dot{x}y + x\dot{y}\right)\dot{\alpha} + m_b g y\cos\beta = \tau_y\end{aligned} \tag{10}$$

$m_b\left(kg\right)$ is the mass of the ball, $J_b\left(kgm^2\right)$ is the rotational moment of inertia of the ball, $J_{P_x}\left(kgm^2\right)$ and $R_b\left(m\right)$ are the rotational moment of inertia of the plate and the radius of the ball; $x\left(m\right)$ and $y\left(m\right)$ are the position of the ball along the x-y-axis; $\dot{x}\left(m/s\right)$ and

$\ddot{x}\left(m/s^2\right)$ are the velocity and acceleration along the x-axis; $\dot{y}\left(m/s\right)$ and $\ddot{y}\left(m/s^2\right)$ are the velocity and acceleration along the y-axis; $\alpha\left(rad\right)$ and $\dot{\alpha}\left(rad/\sec\right)$ are the plate deflection angle, and angular velocity about x-axis; $\beta\left(rad\right)$ and $\dot{\beta}\left(rad/\sec\right)$ are the plate deflection angle and angular velocity about y-axis; $\tau_x\left(Nm\right)$ and $\tau_y\left(Nm\right)$ are the torques on the plate in the x-yaxis.

Equation (7) and (8) governs the movement of the ball on the plate; it also states how the effect of the ball's acceleration depends on the plate's deflection angle and also it's angular velocity; Equation (9) and (10) relates to how the dynamics of the plate's deflection depends on the external driving forces, and the position of the ball (Duan *et al.*, 2009):

Consider the assignment of the state variable as (Fan *et al.*, 2004):

$$X = \left(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8\right)^T = \left(x, \dot{x}, \alpha, \dot{\alpha}, y, \dot{y}, \beta, \dot{\beta}\right)^T \quad (11)$$

The state space equation of the BPS is given as (Fan *et al.*, 2004):

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \\ \dot{x}_5 \\ \dot{x}_6 \\ \dot{x}_7 \\ \dot{x}_8 \end{bmatrix} = \begin{bmatrix} x_2 \\ B\left(x_1 x_4{}^2 + x_4 x_5 x_8 - g\sin x_3\right) \\ x_4 \\ 0 \\ x_6 \\ B\left(x_5 x_8{}^2 + x_1 x_4 x_8 - g\sin x_7\right) \\ x_8 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u_x \\ u_y \end{bmatrix} \quad (12)$$

$$y = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix} \left[X\right] \quad (13)$$

Where:

$$B = \frac{m_b}{\left(m_b + \dfrac{J_b}{R_b{}^2}\right)} \quad (14)$$

In its steady state, the plate is in the horizontal position where the inclination of both angles are equal to zero, if the change of the inclination angles is not much, i.e. $\pm 5^0$, then, the sine function should be represented by its argument (Fabregas *et al.*, 2017). The BPS can be simplified and decomposed into x-y axis as (Umar *et al.*, 2019):

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\\ \dot{x}_4\end{bmatrix}=\begin{bmatrix}x_2\\ B\left(x_1x_4^{\ 2}-g\sin x_3\right)\\ x_4\\ 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\\ x_4\end{bmatrix}+\begin{bmatrix}0\\ 0\\ 0\\ 1\end{bmatrix}\left[u_x\right] \qquad (15)$$

$$\begin{bmatrix}\dot{x}_5\\ \dot{x}_6\\ \dot{x}_7\\ \dot{x}_8\end{bmatrix}=\begin{bmatrix}x_6\\ B\left(x_5x_8^{\ 2}-g\sin x_7\right)\\ x_8\\ 0\end{bmatrix}\begin{bmatrix}x_5\\ x_6\\ x_7\\ x_8\end{bmatrix}+\begin{bmatrix}0\\ 0\\ 0\\ 1\end{bmatrix}\left[u_y\right] \qquad (16)$$

## 3. Materials and Methods

The step by step procedures followed in actualizing the trajectory tracking of the BPS is:

### 3.1. Double Feedback Loop Structure

The double feedback loop structure can be regarded as two distinct systems that operates simultaneously with each other. Hence, similar but different controllers can be applied for controlling each coordinate of the ball's motion (Awtar et al., 2002). The design of the inner loop is done first, this is where the encoder feedback is sent to the dc servo motors for the position control, and the outer loop is designed next based on the transfer function formed between the inner and outer loop. The inner loop and outer loop controllers designed using linear algebraic method by solving a set of Diophantine equation and controller. The inner loop controls the tilt of the plate, and the outer loop controls the ball's position on the plate. Figure 3 shows the double loop feedback structure of the control scheme.

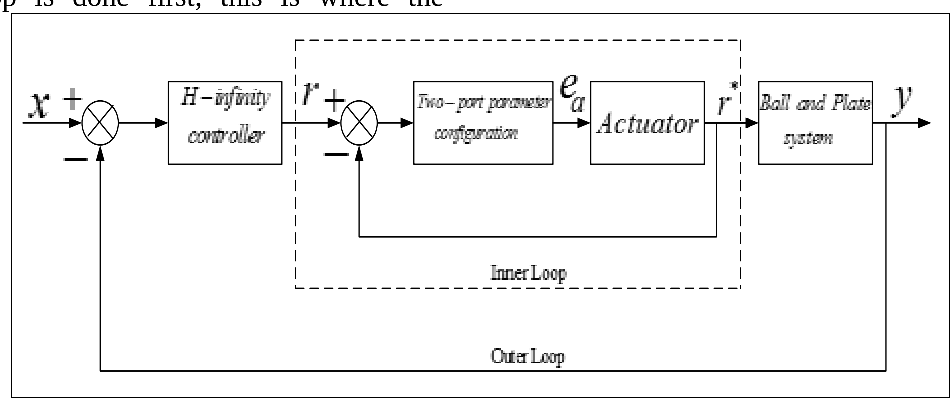



Figure 3: Double feedback loop structure of the control scheme

### 3.2. Inner Loop Design

The design procedure carried out for the inner loop are:

### *I. Determination of Actuator Parameters*

A specified actuator with a permanent DC motor parameters is considered for the design of the inner loop, the relationship between and is (Golnaraghi & Kuo, 2010):

$$\frac{\theta_L}{e_a}=\frac{K_t\frac{N_1}{N_2}}{\left[J_{eq}L_a s^3+\left(J_{eq}R_a+D_{eq}L_a\right)s^2+\left(D_{eq}R_a+K_tK_e\right)s\right]}=T_L \quad (17)$$

The DC servo motors parameters are given based on the following requirements which are; the moment of inertia, the load torque and the speed of the motor. This is given in Table I.

Table I: Parameters of the BPS (HUMUSOFT Ltd., 2012b)

| S/N | Description | Symbol | Unit | Value |
|---|---|---|---|---|
| 1 | Mass of the ball | $m$ | $kg$ | 0.11 |
| 2 | Radius of the ball | R | $m$ | 0.02 |
| 3 | Dimension of the plate (square) | $lxb$ | $m^2$ | 0.16 |
| 4 | Mass moment of inertia of the plate | $J_{Px,y}$ | $kgm^2$ | 0.5 |
| 5 | Mass moment of inertia of the ball | $J_b$ | $kgm^2$ | 1.76e-5 |
| 6 | Maximum velocity of the ball | $V$ | $m/s$ | 0.04 |

Equation (17) is given as (Umar, 2017):

$$\frac{\theta_L}{e_a}=\frac{0.105}{\left[0.47005s^2+421.113s\right]} \quad (18)$$

$$=\frac{0.2234}{s\left(s+895.89\right)}\approx\frac{2.49x10^{-4}}{s} \quad (19)$$

### II. Two-Port Parameter Configuration

The parameter of the two-port configuration was used for the design of the inner loop. A step response which could settle in 0.4 seconds was required in order to find the value of , making use of the Humusoft BPS manual, and also through simulation, the steady state response which is was found to be .The overall optimal ITAE transfer function of the system with a zero position error is given as (Chen, 1995):

$$G_0\left(s\right)=\frac{{\omega_0}^2}{s^2+1.4\omega_0 s+{\omega_0}^2} \quad (20)$$

In order to limit the step response using a preamplifier, an additional gain of 494 was provided, and $G_0(s)$ is implemented using the two-port configuration as shown in Figure 4.

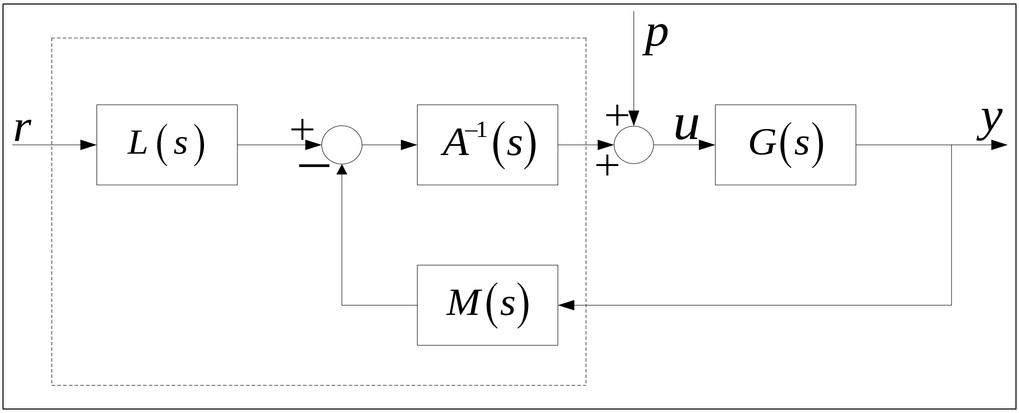


Figure 4: Two-port parameter configuration

Where $L(s)$, $M(s)$ and $A(s)$ are the polynomials that describes the compensator, and $p$ is the input disturbance. By solving the Diophantine equation, the values of the compensator and the DC servo actuator has the values as: (Umar *et al.*, 2018):

$$A(s) = 28 + s \tag{21}$$

$$M(s) = 3252 + s \tag{22}$$

$$L(s) = 3252 \tag{23}$$

### 1.1. *Outer Loop Design*

The outer loop design of the BPS involves the following:

#### I. $H_\infty$ *Controller*

The augmented plant model for $H_\infty$ controller can be constructed as (Dingyu *et al.*, 2007):

$$P(s) = \left[\begin{array}{c:cc} A & B_1 & B_2 \\ \hdashline C_1 & D_{11} & D_{12} \\ C_2 & D_{21} & D_{22} \end{array}\right] \tag{24}$$

And the augmented state description is:

$$\dot{x} = Ax + \begin{bmatrix} B_1 & B_2 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \tag{25}$$

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} C_1 \\ C_2 \end{bmatrix} x + \begin{bmatrix} D_{11} & D_{12} \\ D_{21} & D_{22} \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \tag{26}$$

The Straight forward manipulation of the closed loop transfer function gives:

$$Ty_1u_1(s) = P_{11}(s) + P_{12}(s)\left[I - F(s)P_{22}(s)\right]^{-1} F(s)P_{21}(s) \tag{27}$$

Equation (27) is called the linear fractional transformation (LFT) of the interconnected system. For a robust control, the aim is to get a controller that stabilizes the system, such that:

$$u_2(s) = F(s)\, y_2(s) \tag{28}$$

$$\|Ty_1u_1\|_\infty < 1 \tag{29}$$

The objective of the design is to obtain a robust controller $F_c(s)$ that will guarantee the closed-loop system with an $H_\infty$-norm that bound a positive number $\gamma$, given by (Dingyu *et al.*, 2007):

$$\|Ty_1u_1\|_\infty < \gamma \tag{30}$$

Which implies that the controller can be represented by (Dingyu *et al.*, 2007):

$$F_c(s) = \left[\begin{array}{c:c} A_f & -ZL \\ \hdashline F & 0 \end{array}\right] \quad (31)$$

Where:

$$A_f = A + \gamma^{-2} B_1 B_1^T X + B_2 F + ZLC_2 \quad (32)$$

$$F = -B_2^T X \quad (33)$$

$$L = -YC_2^T \quad (34)$$

$$Z = \left(I - \gamma^{-2} YX\right)^{-1} \quad (35)$$

X and Y are the solutions of the two Algebraic Riccati Equations (AREs), which are (Dingyu *et al.*, 2007):

$$A^T X + XA + X\left(\gamma^{-2} B_1 B_1^T - B_2 B_2^T\right) X + C_1 C_1^T = 0 \quad (36)$$

$$AY + YA^T + Y\left(\gamma^{-2} C_1^T C_1 - C_2^T C_2\right) Y + B_1^T B_1 = 0 \quad (37)$$

The conditions for the existence of an $H_\infty$ controller are as follows (Dingyu *et al.*, 2007):

a. $D_{11}$ is small enough that $D_{11} < \gamma$

b. $X$ is the solution of the controller ARE, which is positive-definite;

c. $Y$ is the solution of the observer ARE, which is positive-definite;

d. $\lambda_{\max}(XY) < \gamma^2$ shows that the eigenvalues of the product of the two Riccati equation solution matrices are all less than $\gamma^2$.

The optimal criterion in the design of the optimal $H_\infty$ controller, is given as (Dingyu *et al.*, 2007):

$$\max_{\gamma} \| Ty_1 u_1 \|_\infty < \frac{1}{\gamma}$$

(38)

## II. $H_\infty$ Mixed Sensitivity Function

In the design of the $H_\infty$ optimal control, using the mixed sensitivity problem, the weighting functions $W_1(s)$, $W_2(s)$ and $W_3(s)$ are used for shaping the plant model $G(s)$. The weighting function $W_1(s)$, penalises the error signal, $W_2(s)$ penalises the input signal and $W_3(s)$ penalises the output signal (Hossain, 2007). This is shown in Figure 5.

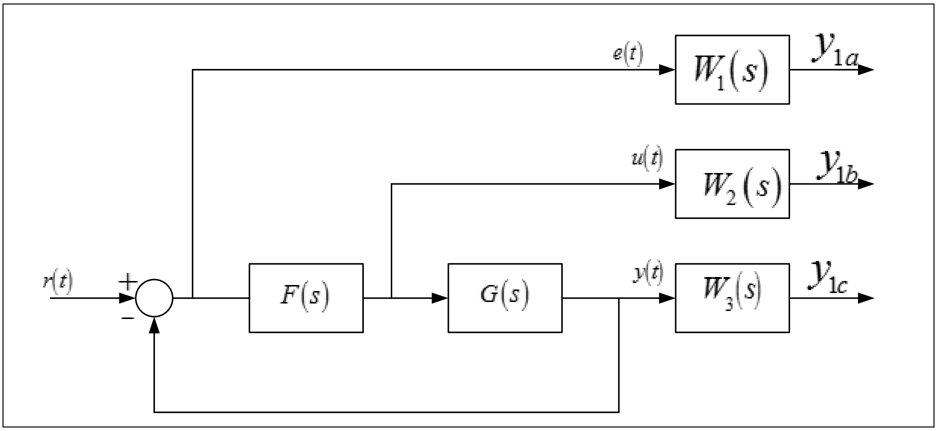


Figure 5: Mixed sensitivity problem

The augmented plant model $P(s)$ is:

$$P(s)=\left[\begin{array}{c:c} W_1 & -W_1G \\ 0 & W_2 \\ 0 & W_3G \\ \hdashline I & -G \end{array}\right] \tag{39}$$

The linear fractional transformation (LFT) of the mixed sensitivity problem $Ty_1u_1$, the sensitivity transfer function $S(s)$ and the complementary sensitivity transfer function $T(s)$ are given as (Dingyu *et al.*, 2007):

$$Ty_1u_1=\begin{bmatrix} W_1S \\ W_2FS \\ W_3T \end{bmatrix} \tag{40}$$

$$S(s)=\left[1+F(s)G(s)\right]^{-1} \tag{41}$$

$$T(s)=1-S(s)=F(s)G(s)\left[1+F(s)G(s)\right]^{-1} \tag{42}$$

$F(s)$ is the controller, $S(s)$ and $T(s)$ are known as the sensitivity and complementary transfer functions.

### *II. Determination of the $H_\infty$ Controller*

The weighting functions $W_1(s)$, $W_2(s)$ and $W_3(s)$ for the control of the ball on the plate were selected after extensive simulation and fine tuning as:

$$W_1(s) = \frac{100\left(1.5s^2 + 12.64s + 18.49\right)}{100\left(1.5s^2 + 103.2s + 18.49\right)} \quad (43)$$

$$W_2(s) = 1 \quad (44)$$

$$W_3(s) = \frac{s^2}{100} \quad (45)$$

**4. Graphical Use Interface**

Graphical User Interface (GUI), refers to the universal idea of buttons, icons, etc., that can be visually presented to a user as a "front-end" of a software application (Patrick & Thomas, 2003). GUI contains a figure window which consists of menus, texts, graphics, buttons etc., that a user can make use of interactively with the aid of the mouse and keyboards. There two main procedures in creating a GUI are (Hunt *et al.*, 2014):

i. Design of its layout, and
ii. To write callback functions which performs the desired operations when different features are selected by the user.

The main advantage of GUIs is its provision of a means through which the individuals can communicate with the aid of a computer without the use of a programming commands. The GUI graphics objects components can be classified in two classes (Hunt *et al.*, 2014):

i. User interface controls *(uicontrols)*
ii. User interface menus *(uimenus)*

The *uicontrols* and *uimenus* is used to create an intuitive, informative and a visually pleasing GUIs when in combination with other graphic objects. In order to have access to them, two approaches are employed; the low-level, bottom-up approach in which use of skills to handle graphics and write M-files that implement the GUI. The other approach is in the use of MATLAB's Graphical User interface Development Environment (GUIDE), which is high-level, extremely easy to use and a powerful technique; an outstanding tool that aids in the development of GUIs , and also takes into consideration of much of the "bookkeeping" which is regularly associated with the development of the GUI (Hunt *et al.*, 2014).

**5. Results and Discussions**

Simulations results for the inner loop design, outer loop design and trajectory tracking of the ball-on-the- plate is given in the following sub-section. However, the simulation results were obtained from MATLAB 2018a simulation environment.

***5.1 Inner Loop Results***

The actuator's step response is shown in Figure 6.

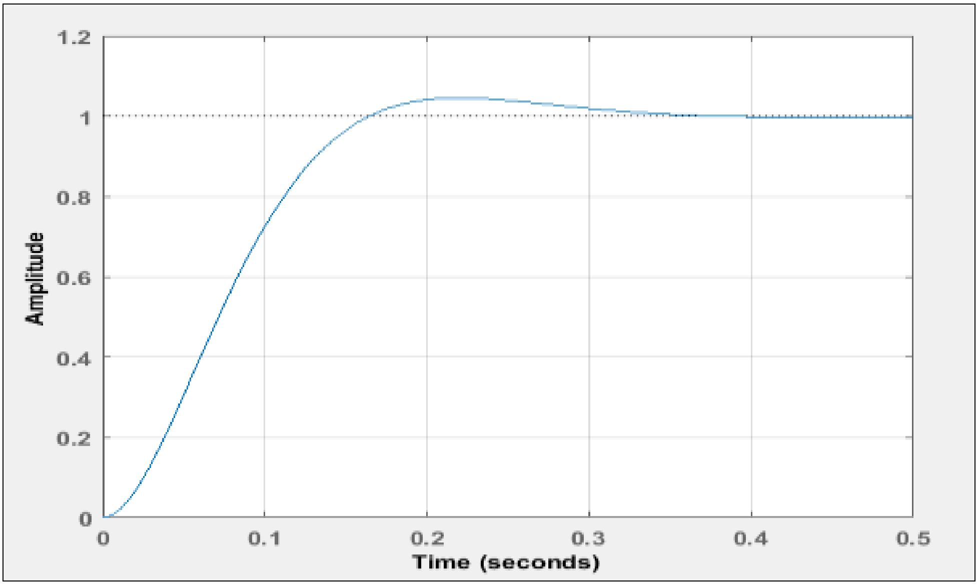



Figure 6: Actuator Step Response

Table II shows the properties of the actuator

Table II: Properties of the actuator

| **System Response** | **Value** |
|---|---|
| Settling Time (sec) | 0.2989 |
| | |
| Overshoot (%) | 4.5986 |

From Table II, the actuator's settling time of the actuator is 0.2989 seconds, this shows that the plate should settle before 0.4 seconds that was set for it. However, the actuator $U(s)$ due to a step input should not exceed the DC motor rated voltage, which is 75V. Also, the actuator with open parameter (rated power and voltage) step response is shown in Figure 7.

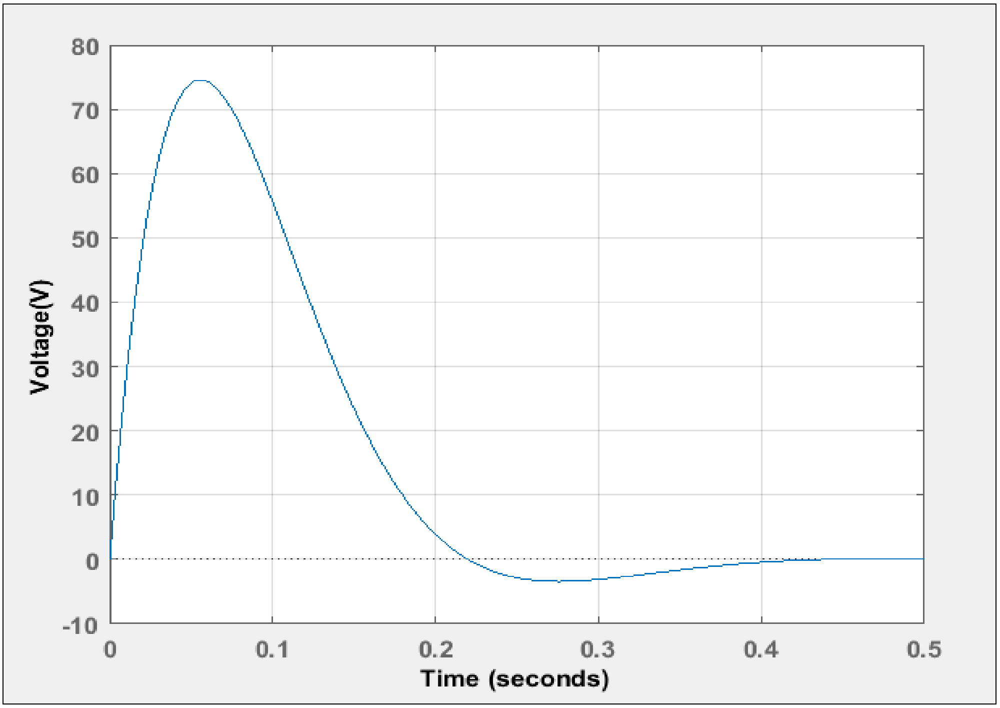



Figure 7: Actuator with open parameters Step Response

The properties of the actuator with open parameters is shown in Table III

Table III: Properties of the Actuator with Open Parameters

| **Actuator System Response** | **Value** |
| --- | --- |
| Settling Time (sec) | 0.3546 |
| Peak Voltage (V) | 74.5631 |

From Table III, it can be seen that the stability of the plate is at 0.3546 seconds. The peak voltage which is 74.5631V, is closer to the rated voltage of 75V, which invariably showed that for a proper design, the DC motor actuator should have the following properties as given in Table III.

### *5.2 Outer Loop Results*

The designed $H_\infty$ controller is:

$$Gc = \frac{23622(s+1.631)(s+0.2213)(s+0.1794)}{(s+1109)(s+25.82)(s+0.9012)(s+0.3308)} \qquad (46)$$

The $H_\infty$ controller step response is shown in Figure 8.

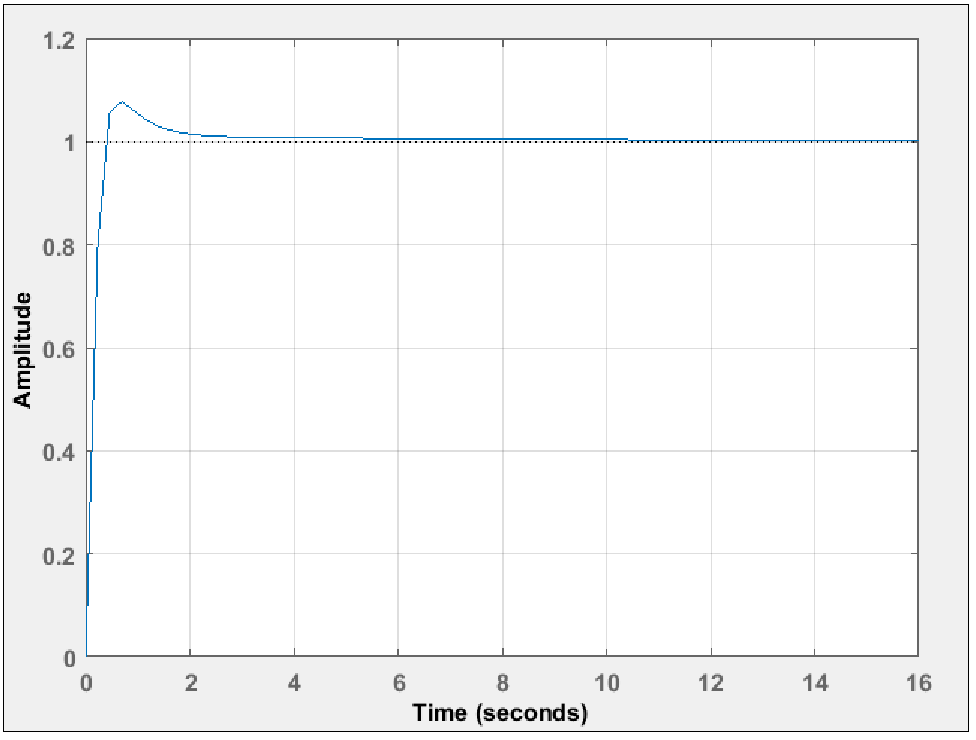



Figure 8: controller step response

From Figure 8, $H_\infty$ controller has the following properties given in Table IV.

Table IV: Properties of the H-infinity Controller

| H-infinity Controller System Response | Value |
|---|---|
| Settling Time (sec) | 1.7087 |
| Overshoot (%) | 7.7246 |

From Table IV, the $H_\infty$ controller stabilized the ball at 1.7087 seconds, with an overshoot of 7.7246 %. This gives a good indication that the ball was tracked on the reference path on the plate.

### *5.3 Trajectory Tracking Results*

Figure 9 shows a figure interface of the GUI of the plot of the trajectory of X-position with respect to the Y-position. A circular trajectory of radius 0.4 m, and a sinusoidal signal of a reference input of $x = 0.4(1 - \cos\omega t)$ and

$y = 0.4(\sin \omega t)$ was considered, and also used for the demonstration of the trajectory tracking performance of the ball. The angular frequency of the referenced sinusoidal signal used was 1.57 rad/sec.

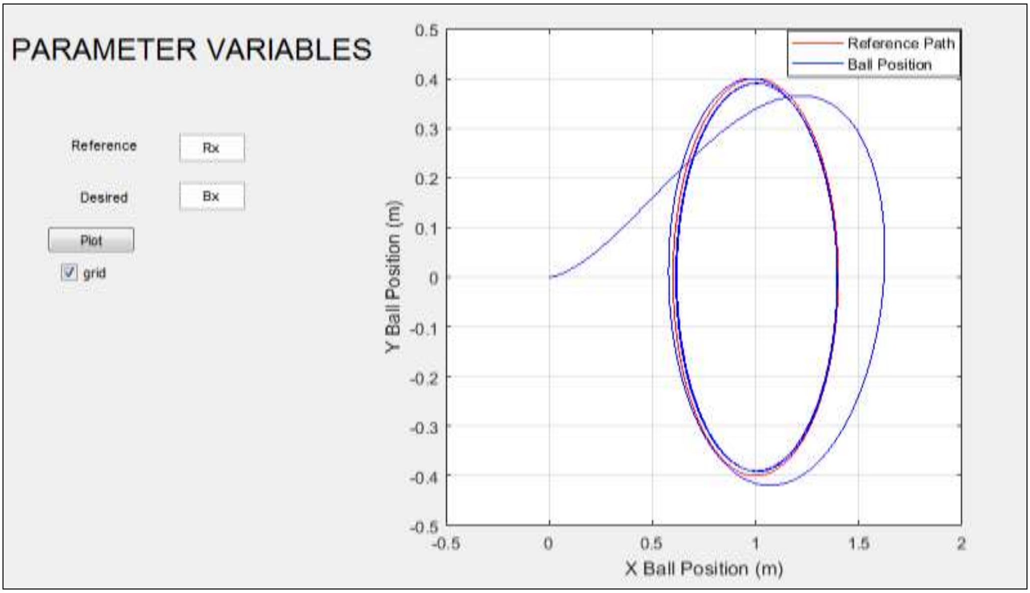


Figure 9: GUI circular trajectory tracking using H-infinity controller

The ball was allowed to track a circular trajectory at a frequency of 0.52 rad/sec at a complete revolution of 12 seconds. Increasing the speed to 0.9 rad/sec, at a complete revolution of 7 seconds, the trajectory tracking error also increased.

However, it was observed that using the H-infinity controller, the steady state tracking error of the ball is 0.0095 m, which depicts that the ball was able to track the referenced sinusoidal signal with a trajectory tracking error of 0.0095 m.

## 6. Conclusion

The position and trajectory tracking control of the Ball and Plate System (BPS) based GUI using a double feedback loop structure i.e. a loop within a loop has been presented. The inner loop was designed using linear algebraic method by solving a set of Diophantine equation, while outer loop was designed using sensitivity function. Simulation results showed that the controllers has strong adaptability, robustness and high control performance for the BPS. The ball was able to settle with a good settling time and overshoot. However, future research work will be in the direction of optimizing the weighting parameters of the controller optimally by using artificial intelligent technique like bat algorithm (BA) and cuckoo search optimization algorithm (CSO).

## Acknowledgment

The authors express their deep

appreciation to the Control/Computer Research Group of the Computer Engineering Department, Ahmadu Bello University, Zaria, Nigeria. And all those in Tuesdays meetings, where academic freedom and discourse are at its best.

## References

Ali, E., & Aphiratsakun, N. (2015). AU Ball on Plate Balancing Robot. Paper presented at the IEEE International Conference on Robotics and Biomimetics (ROBIO), Zhuhai, China

Aphiratsakun, N., & Otaryan, N. (2016). Ball On The Plate Model Based on PID Tuning Methods. Paper presented at the 13th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), Chiang Mai, Thailand.

Awtar, S., Bernard, C., Boklund, N., Master, A., Ueda, D., & Craig, K. (2002). Mechatronic design of a ball-on-plate balancing system. Mechatronics, 12(2), 217-228.

Bang, H., & Lee, Y. S. (2018). Implementation of a Ball and Plate Control System using Sliding Mode Control. IEEE Access, 14(8), 1-8. doi: 10.1109/ACCESS.2018.2838544

Bigharaz, M., Safaei, F., Afshar, A., & Suratgar, A. (2013). Identification and Nonlinear Control of a Ball-Plate System Using Neural Networks. Paper presented at the 3rd International Conference on Control, Instrumentation, and Automation (ICCIA). , Tehran, Iran.

Borah, M., Majhi, L., Roy, P., & Roy, B. K. (2014). Design of a Fractional Order PD Controller Tuned by Firefly Algorithm for Stability Control of the Nonlinear Ball and Plate System. Paper presented at the IEEE International Conference on Advanced Communication Control and Computing Technologies, Ramanathapuram, India.

Chen, C.-T. (1995). Analog and Digital Control System Design: Transfer-function, State-space, and Algebraic Methods. New York, USA: Oxford University Press, Inc.

Cheng, C.-C., & Chou, C.-C. (2016). Fuzzy-Based Visual Servo with Path Planning for a Ball-Plate System. International Symposium on Intelligent Computing Systems (ISICS), 97-107. doi: 10.1007/978-3-319-30447-2_8

Cheng, C.-C., & Tsai, C.-H. (2016). Visual Servo Control for Balancing a Ball-Plate System. International Journal of Mechanical Engineering and Robotics Research, 5(1), 28-32.

Cherubini, A., Colafrancesco, M., Oriolo, G., Freda, L., & Chaumette, F. (2009). Comparing appearance-based controllers for nonholonomic navigation from a visual memory. Paper presented at the ICRA 2009 Workshop on safe navigation in open and dynamic environments: application to autonomous vehicles, Kobe, Japan.

Das, A., & Roy, P. (2017). Improved Performance of Cascaded Fractional-Order SMC over Cascaded SMC for Position Control of a Ball and Plate System. IETE Journal of Research, 63(2), 238-247. doi: 10.1080/03772063.2016.1258336

Debono, D., & Bugeja, M. (2015). Application of Sliding Mode Control to the Ball and Plate Problem. Paper presented at the 12th International Conference on Informatics in Control, Automation and Robotics (ICINCO), 2015, Colmar, Alsace, France.

Dingyu, X., YangQuan Chen, & Derek P., A. (2007). Linear Feedback Control; Analysis and Design with MATLAB (Vol. 3). 3600 Market Street, 6th floor, Philadelphia, PA 19104-2688, USA: Society for Industrial and Applied Mathematics.

Dong, X., Zhang, Z., & Chen, C. (2009). Applying genetic algorithm to on-line updated PID neural network controllers for ball and plate system. Paper presented at the Innovative Computing, Information and Control (ICICIC), 2009 Fourth International Conference on.

Duan, H., Tian, Y., & Wang, G. (2009). Trajectory Tracking Control of Ball and Plate System Based on Auto-Disturbance Rejection Controller. Paper presented at the 7th Asian Control Conference, ASCC 2009. , Hong Kong, China.

Dušek, F., Honc, D., & Sharma, K. R. (2017). Modelling of Ball and Plate System Based on First Principle Model and Optimal Control. Paper presented at the 21st International Conference on Process Control (PC), 2017 Strbske Pleso, Slovakia

Escobar, L. A. M., Almeida, M. A. G., Quintero, O. E. C., Acosta, J. A. R., & Espin, D. F. P. (2017). A comparative analysis among different controllers applied to the experimental ball and plate system. Paper presented at the 2017 International Conference on Information Systems and Computer Science (INCISCOS), Quito, Ecuador

Fabregas, E., Chacon, J., Dormido-Canto, S., Farias, G., & Dormido, S. (2017). Virtual and Remote Laboratory with the Ball and Plate System. IFAC-PapersOnLine, 50(1), 9132-9137. doi: https://doi.org/10.1016/j.ifacol.2017.08.1716

Fan, X., Zhang, N., & Teng, S. (2004). Trajectory planning and tracking of ball and plate system using hierarchical fuzzy control scheme. Fuzzy Sets and Systems, 144(2), 297-312.

Farooq, U., Gu, J., & Luo, J. (2013). On the Interval Type-2 Fuzzy Logic

Control of Ball and Plate System. Paper presented at the 2013 IEEE International Conference on Robotics and Biomimetics (ROBIO).

Fei, Z., Xiaolong, Q., Xiaoli, L., & Shangjun, W. (2011). Modeling and PID Neural Network Research for the Ball and Plate System. Paper presented at the 2011 International Conference on Electronics, Communications and Control (ICECC).

Galvan-Colmenares, S., Moreno-Armendáriz, M. A., Rubio, J. d. J., Ortíz-Rodriguez, F., Yu, W., & Aguilar-Ibáñez, C. F. (2014). Dual PD Control Regulation with Nonlinear Compensation for a Ball and Plate System. Mathematical Problems in Engineering, 2014, 1-10. doi: 10.1155

Golnaraghi, F., & Kuo, B. C. (2010). Automatic Control Systems (9th ed. Vol. 2): John Wiley & Sons, Inc.

Han, K., Tian, Y., Kong, Y., Li, J., & Zhang, Y. (2012). Tracking control of ball and plate system using a improved PSO on-line training PID neural network. Paper presented at the 2012 IEEE International Conference on Mechatronics and Automation.

Hossain, S. (2007). Design of a robust controller for a magnetic levitation system. Wichita State University.

HUMUSOFT Ltd. (2012a). Educational Manual for CE 151 Ball and Plate Apparatus: Humusoft.

HUMUSOFT Ltd. (2012b). User's Manual for CE151 Ball and Plate Apparatus.

Hunt, B. R., Lipsman, R. L., Rosenberg, J. M., Coombes, K. R., Osborn, J. E., & Stuck, G. J. (2014). A Guide to MATLAB®: for beginners and experienced users (2 ed.). Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo: Cambridge University Press.

Hussein, S., Muhammed, B., Sikiru, T., Umoh, I., & Salawudeen, A. (2017). Trajectory Tracking Control of Ball on Plate System Using Weighted Artificial Fish Swarm Algorithm Based PID. Paper presented at the IEEE 3rd International Conference on Electro-Technology for National Development (NIGERCON), 2017 Owerri, Nigeria

Jafari, H., Rahimpour, A., Pourrahim, M., & Hashemzadeh, F. (2012). Linear Quadratic Gaussian Control for ball and plate system. Paper presented at the 2012 International Conference on Computer, Control, Education and Management (CCEM 2012), Dubai, United Arab Emirates.

Kassem, A., Haddad, H., & Albitar, C. (2015). Commparison Between Different Methods of Control of Ball and Plate System with 6DOF Stewart Platform. IFAC-PapersOnLine, 48(11), 47-52.

Lin, C. E., Liou, M.-C., & Lee, C.-M. (2014). Image Fuzzy Control on

Magnetic Suspension Ball and Plate System. International Journal of Automation and Control Engineering, (IJACE), 3(2), 35-47. doi: 10.14355/ijace.2014.0302.02

Lin, H.-Q., Cui, S.-G., Geng, L.-H., & Zhang, Y.-L. (2014). H∞ Controller Design for A Ball and Plate System Using Normalized Coprime Factors. Paper presented at the The 26th Chinese Control and Decision Conference (CCDC), , Changsha, China

Liu, H., & Liang, Y. (2010). Trajectory tracking sliding mode control of ball and plate system. Paper presented at the 2nd International Asia Conference on Informatics in Control, Automation and Robotics (CAR), 2010, Wuhan, China.

Ming, B., Yantao, T., & Yongxiang, W. (2011). Decoupled fuzzy sliding mode control to ball and plate system. Paper presented at the Intelligent Control and Information Processing (ICICIP), 2011 2nd International Conference on.

Mochizuki, S., & Ichihara, H. (2013, July 17-19). I-PD controller design based on generalized KYP lemma for ball and plate system. Paper presented at the European Control Conference (ECC), 2013 Zurich, Switzerland.

Mohammadi, A., & Ryu, J.-C. (2018). Neural network-based PID compensation for nonlinear systems: ball-on-plate example. International Journal of Dynamics and Control, 1-11. doi: https://doi.org/10.1007/s40435-018-0480-5

Morales, L., Camacho, O., Leica, P., & Chávez, D. (2017). A Sliding-Mode Controller from a Reduced System Model: Ball and Plate System Experimental Application. Paper presented at the 14th International Conference on Informatics in Control, Automation and Robotics (ICNCO 2017), Madrid-España.

Mukherjee, R., Minor, M. A., & Pukrushpan, J. T. (2002). Motion Planning for a Spherical Mobile Robot: Revisiting the Classical Ball-Plate Problem. Journal of Dynamic Systems Measurement and Control, 124, 502-511. doi: 10.1115/1.1513177

Negash, A., & Singh, N. P. (2015). Position Control and Tracking of Ball and Plate System Using Fuzzy Sliding Mode Controller. Paper presented at the Afro-European Conference for Industrial Advancement.

Oravec, M., & Jadlovská, A. (2015). Model Predictive Control of a Ball and Plate laboratory model. Paper presented at the IEEE 13th International Symposium on Applied Machine Intelligence and Informatics (SAMII), 2015 Slovakia.

Oriolo, G., & Vendittelli, M. (2005). A Framework for the Stabilization of General Nonholonomic Systems With an Application to the Plate-Ball Mechanism. IEEE Transactions on Robotics, 21(2), 162-175.

Roy, P., Acharjee, S., Ram, A., Das, A., Sen, T., & Roy, B. K. (2016a). Cascaded Sliding Mode Control for Position Control of a Ball in a Ball and Plate System. Paper presented at the IEEE Students' Technology Symposium (TechSym), India.

Roy, P., Das, A., & Roy, B. K. (2016b). Cascaded fractional order sliding mode control for trajectory control of a ball and plate system. Transactions of the Institute of Measurement and Control, 1-11. doi: 10.1177/0142331216663826

Roy, P., Kar, B., & Hussain, I. (2015). Trajectory Control of a Ball in a Ball and Plate System Using Cascaded PD Controllers Tuned by PSO. Paper presented at the Proceedings of Fourth International Conference on Soft Computing for Problem Solving.

Saud, L. J., & Alwan, M. M. (2017). Design and Implementation of Classical Sliding Mode Controller for Ball and Plate System. Journal of Engineering, 23(6), 74-92.

Singh, R., & Bhushan, B. (2018). Real-time control of ball balancer using neural integrated fuzzy controller. Artificial Intelligence Review, 1-18. doi: https://doi.org/10.1007/s10462-018-9658-7

Suleiman, H. U., Mu'azu, M. B., Zarma, T. A., Salawudeen, A. T., Thomas, S., & Galadima, A. A. (2018). Methods of Chattering Reduction in Sliding Mode Control: A Case Study of Ball and Plate System. Paper presented at the 2018 IEEE 7th International Conference on Adaptive Science & Technology (ICAST), Accra, Ghana

Umar, A. (2017). Development of a Position and Trajectory Tracking Control of Ball and Plate System using a Double Feedback Loop Structure. (Masters of Science Thesis), Department of Electrical and Computer Engineering, Faculty of Engineering, Ahmadu Bello University, Zaria, Published.

Umar, A., Mu'azu, M. B., Usman, A. D., Musa, U., Ajayi, O.-o., & Yusuf, A. M. (2019). Linear Quadratic Gaussian (LQG) Control Design for Position and Trajectory Tracking of the Ball and Plate System. Computing & Information Systems, 23(1).

Umar, A., Muazu, M. B., Aliyu, U. D., Musa, U., Haruna, Z., & Oyibo, P. O. (2018). Position and Trajectory Tracking Control for the Ball and Plate System using Mixed H∞ Sensitivity Problem. Covenant Journal of Informatics and Communication Technology, (CJICT), 6(1), 1-15.

Wang, Y., Li, X., Li, Y., & Zhao, B. (2012). Identification of ball and plate system using multiple neural network models. Paper presented at the International Conference on System Science and Engineering

(ICSSE), 2012.

Yıldız, H. A., & Gören-Sümer, L. (2017). Stabilizing of Ball and Plate System Using an Approximate Model. IFAC-PapersOnLine, 50(1), 9601-9606. doi: https://doi.org/10.1016/j.ifacol.2017.08.1688

Zeeshan, A., Nauman, N., & Khan, M. J. (2012). Design, Control and Implementation of a Ball on Plate Balancing System. Paper presented at the IEEE 9th International Bhurban Conference on Applied Sciences & Technology (IBCAST), Islamabad, Pakistan.

*Covenant Journal of Informatics & Communication Technology. Vol. 7 No. 1, June, 2019*

**ISSN: p2354 – 3566 e 2354 – 3507 DOI: 10.20370/prwp-re56**

**An Open Access Journal Available Online**

# Optimized Industrial Automation Network for Efficient Productivity Using Quality of Service Policy Mechanism (QPM)

**Emmanuel Utochukwu Ogbodo & Ifeyinwa Faith Ogbodo**

Nnamdi Azikiwe University, Awka, Nigeria
*Contact(s).* ogbodoeu@ieee.org, ifeyinwaobudulu@yahoo.com

**Received: 08. 03. 2019 Accepted: 14. 05. 2019 Date of Publication: June, 2019**

***Abstract***— In this paper, the complexity of industrial automation network when compared to the traditional IT corporate organization network or campus network, was first described. The challenges and components of industrial automation network have been highlighted. Hence, in order to overcome the challenges in the industrial automation network, the network was optimized by incorporating Quality of Service (QoS) Policy Mechanism (QPM) model in the network design. Existing mechanisms such as transmission control protocol (TCP) to deal with these problems, and the limitations of relying only on TCP were then discussed. The potential to improve the industrial automation network in the perspective of industrial internet of things (IIoT) has been reported in this paper as a further investigation in the future works. Simulation results were presented which showed that the optimized industrial automation network using QoS Policy Mechanism model gives higher performance throughput than the congestion control algorithm of the conventional TCP and the traditional network.

***Keywords/Index Terms*** — Differentiated Service (DiffServ), Industrial Automation Network, Modeling and Simulation, Quality of Service (QoS), QoS Policy Mechanism (QPM).

## 1. Introduction

One of the most crucial building blocks of Industrial automation network and control systems is Quality of Service (QoS). According to RFC2386 (Crawley *et al.*, 1998). QoS could be defined as a set of service requirements to be met by the network while transporting a packet of data stream from source to destination. In line with the notion of

QoS, is an agreement or a guarantee by the network to provide a set of measurable pre-specified service attributes to the user in terms of delay, jitter, available bandwidth, packet loss, etc. Generally, organizational or industrial automation network are designed to support the best-effort service with no guarantees of associated QoS. Therefore, when a packet is lost in a network, the sender simply retransmits the lost packet. QoS guarantees a certain level of performance requirement to a data flow in accordance with requests from the application program. QoS guaranteed are important if the network performance is critical, especially for real-time industrial automation processes and control systems deployed in a large variety of industries, such as automotive, pharmaceuticals, consumer goods, pulp and paper, oil and gas, and energy.

Industrial automation processes and control systems are very demanding because it encompasses so many process plants/production facilities and network infrastructure integration. For example, production facilities may be of a very simple device with limited software and processing capabilities, which makes them susceptible to network-related disruptions or poor communication. In addition, a very quickly changing manufacturing process for example, a paper mill, or complex automation for example, multi-axis robot, demand very high levels of determinism in the industrial automation and control system. These then require real-time communication from the network infrastructure. Hence the network infrastructure deployment to support Industrial Automation Processes is quite complex and more challenging than traditional IT network infrastructure for corporate organization or campus network. This is because most manufacturing plants and process control operations require response at a very fast rate in Nano seconds; consequently, any poor network deployment may hamper its efficient operations.

Furthermore, industrial automation process and control system contains the following:

- Enterprise Area such as enterprise applications to exchange production and resource data. This is where the centralized IT systems and functions exist.
- Enterprise resource management: business-to-business, and business-to-customer services typically reside at this area. Often user's access systems exist here. For example, end-hosts access a certain resource (such as an ERP, SAP or Oracle application or webpage from www.ieee.org, a video on YouTube, etc.,) on the Internet. It is important to ensure that they do not overwhelm network infrastructure devices (such as routers, control systems servers etc.), and are able to efficiently utilize network resources, and achieve fairness.

Poor QoS of network controlled tems architecture in an industrial automation process ecosystem can lead to network congestion which can be devastating for a data transmission system as it manifests itself as exhaustion of can be CPU, buffer space and bandwidth etc. Though Network Quality of Service (QoS) and advance congestion control protocol to handle the problem of congested network in an industrial automation process ecosystem has been a difficult target to achieve for quite a while. Due to this difficulty in the achievement, QoS has not been widely deployed in today's industrial automation networks. Therefore, the three most commonly adopted techniques to provide congestion control and QoS today are physical network isolation, network over provisioning and restricting certain nodes to transmit at the maximum capacity. Data Center and Network Operating Centers (NOC), for instance, have dedicated networks with specialized hardware and communication protocols for each class of traffic, e.g., Fiber Channel for storage, Infiniband for High Performance Computing (HPC) traffic and Ethernet channel for low traffic. In some cases, networks are highly overprovisioned by subscribing for higher bandwidth as large as more than 5 times in order to support the required QoS to serve the entire network fabric. However, these solutions do not only lead to increased installation costs but also significant increase in management and maintenance costs. In addition, multiple dedicated networks cannot leverage statistical multiplexing of traffic from different applications leading to poor utilization of available network resources even for low traffic resources that are critical to the operation of the system. These resources and best effort network service.

To overcome the challenges stated above, the problem of congestion control in an industrial automation network is approached from the perspective of mechanism design. The design of network congestion control and QoS mechanism have been recently getting lots of attention as it is highly desirable to serve traffic from multiple applications and large scale industrial network so as to optimize the flow of information in an industrial automation processes.

## 2. Related Works

In this section, we review a number of distinct approaches of congestion control and QoS which have recently emerged in various perspectives. Most of the network congestion control mechanisms use the TCP as a network congestion control protocol (Jacobson, 1998). TCP was very helpful preventing congestion in the early time of the Internet and before the emergence and widespread of other types of network and networking technologies evolution.

In spite of its success in avoiding congestion in the early times of the Internet, TCP is now increasingly difficult to withstand the growing Internet and network technologies. In addition, TCP either under-utilizes or over-utilizes the network bandwidth causing the download time to be too long than necessary. The limitation of TCP in congestion control ovehigh bandwidth consuming product networks has been reported in (Brakmo *et al.*, 1994), (Lakshman & Madhow, 2005), (Katabi *et al.*, 2002). It was showed that many packet losses can result in throughput degradation. The same papers also showed that TCP is not suitable towards flows with high round trip delays. TCP is also not good for short-lived flows as seen in (Cristianodi, 2008), since the limited bandwidth is dominated by long-lived flows with large grown window size. However, TCP is now showing performance

Other works as in (Chen *et al.*, 2002; Lakshman & Upamanyu, 2005; Cristianodi, 2008) handled QoS support based on the DiffServ architecture by employing the implementation of Bandwidth Broker (BB) framework which is a QoS management framework that eases the extendibility of other QoS mechanisms such as Multiprotocol Label Switching (MPLS).

## 3. Methodology

### 3.1 Overview

The method adopted in the context of QoS Policy Mechanism (QPM) model for optimization of industrial automation network is modeling and simulation based on discrete event systems. A

limitations and the need for new transport protocol designs has become increasingly important (Bonald *et al.*, 2000), (Yee-Ting, 2007). This need has risen from TCP's inability to meet the challenges brought about by the tremendous growth in the range of link capacities, latencies, and Bit-Error Rates (BER) and also due to increased diversity in applications and their requirements especially in industrial automation process applications.

model is the body of information about a system gathered for the purpose of studying the system. The information that will be gathered in the design of this work is mainly network and QoS parameters. Hence the method of modeling and simulation will be used which is based on discrete event system specification formalism- DEVS, adopted from (Wainer & Rodrigo, 2011). DEVS combines the advantages of a practical approach with the rigor of a formal method; in which one consistently use models throughout the development cycle as shown in the figure 1.

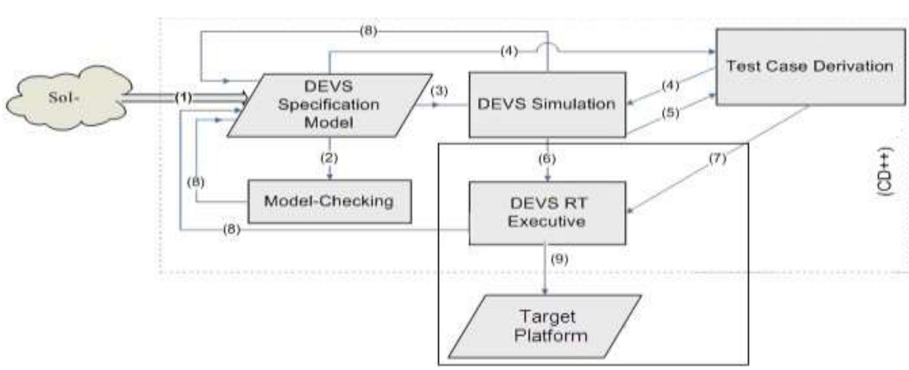


*Figure 1. Discrete event modeling development cycle*

### *3.2QoS Policy Mechanism (QPM)*

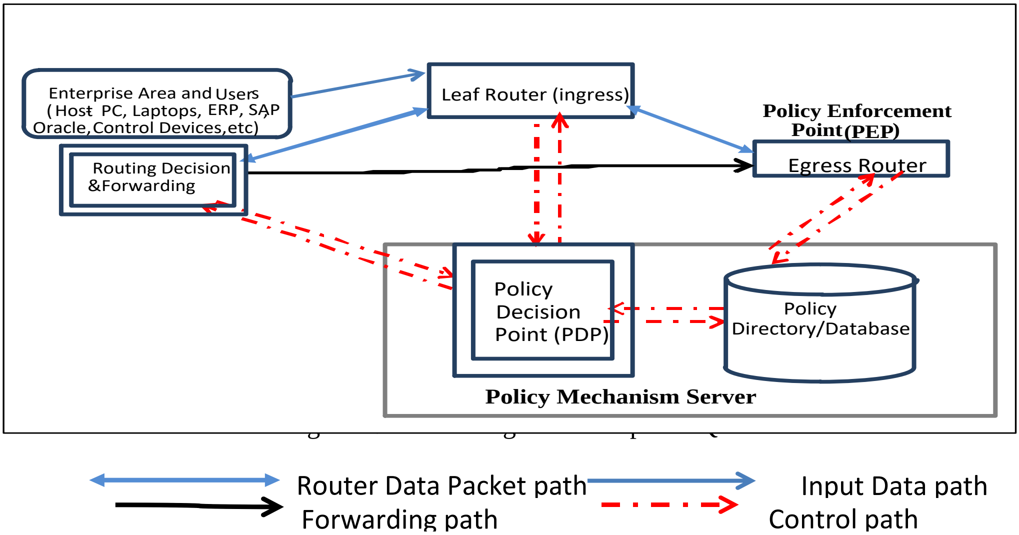
### *3.3 model*

The model of QPM in an Industrial Automation network environment will address network congestion problems, network scalability, manufacturing plants and server centric failure. The model will be integrated in the Enterprise Composite NOC Model for an industrial automation processes. However, it will be based on Differentiated Services (DiffServ) Client-Server Architecture. Differentiated Services (DiffServ) is a proposed architecture for the Internet to support variable QoS requirements using a simple classification scheme. Unlike its counterpart model of IntServ (Integrated Services), the DiffServ framework does not need to maintain large state information in core routers, and only carries out aggregate resource reservation at edge routers. Therefore, DiffServ calls for a very special routing Framework and QoS from IntServ. Hence the QoS parameter such as bandwidth, packet loss, delay, jitter and latency are measurable quantities to be considered in this model. These parameters will be used in the evaluation of this work. The QPM model to be integrated in an Enterprise Composite NOC Model involves the following:

(1) Policy Mechanism Server consisting Policy Decision Point (PDP) and Policy Directory/Database.

(2) Policy Enforcement Point (PEP) comprising the edge routers and core (Routing Decision Entity). Rules are stored in the Policy Directory in a well-understood format or schema. These rules could specify for instance, the service category to be employed for a particular application, how much bandwidth is allocated to a particular flow or Type of Service (ToS) category, etc. The rules regulate access and use of network resources. The PDP entity downloads the policy rules.

The Routing Decision entity maintains the normal topology database to keep routers updated about changes in the network and to minimize routing between routers. It used the topology database to calculate QoS guaranteed routes and fast network convergence. It also inspects the DiffServ Code Point in the IP packet header to determine where to send the packet next and carries out forwarding. The edge router (ingress/egress) encounters packets flowing across the network by classifying, marking, dropping and shaping. It queries the decision entity for specific actions that are to be applied in conditioning the packet stream. The block diagram for this design architecture is illustrated in Figure 2. This architecture supports the outsourcing of policy decision making to a separate Policy Decision Point resident on a specialized policy mechanism server. The next section shall elucidate on the block diagram of the proposed design model.




### *3.4 Description of the Component of the QPM Model Block Diagram*

The various components that made up the QPM model consisted of the following:

- The Policy Decision Point (PDP) - is a Linux software entity that manages resources for IP QoS services. It is responsible for control decisions according to a Policy Directory/Database. Based on such decisions it configures the edges and routers within the network domain. The algorithm is shown below:
- Traffic originating from the Enterprise Area and an end-host reached the ingress-router for being forwarded.
- The ingress-router finds that the priority information for the (IP, Application Type) pair and caches it. The ingress-router contacts the QoS PDP (through NETCONF PROTOCOL), requesting for the priority information.
- The QoS PDP, in turn, contacts the Directory Service (Policy Database) to query for the same.
- After receiving the response from the directory, the PDP return the corresponding priority back to the ingress router.
- The ingress-router thus marks the traffic appropriately.
- All the traffic with the same ToS field is handled in a similar way at the core-routers, in conformance with the DiffServ architecture.

### 3.5 Discrete Event Simulation with OPNET IT Guru Academic Edition

OPNET IT Guru Academic edition is used for simulation of Network. OPNET Modeler is the industry's leading network development software first introduced in 1986 by MIT graduate (OPNET Technologies, 2003; Hassan & Jain, 2003). OPNET allows to design and study communication networks, devices, protocols, and application. Modeler is used by the world's most prestigious technology organizations to accelerate the research and development (R&D) process.

## 4. Simulation Testbed for QPM Model

During the implementation stage of this research, the QPM model was simulated using OPNET IT Guru as a simulation tool. As stated earlier in the previous chapter, OPNET is an object-oriented modeling and simulation tool with Graphical User Interface (GUI) that enable relatively easy means of simulation and developing models from the actual world network. The experiment of the simulation testbed is shown in Figure 3 considering the QPM block diagram of Figure 2.

Experiments were performed over this testbed in two different scenarios viz: proposed QPM model scenario and existing network scenario without the model. The scenario for the proposed QPM model, the simulation was configured as discrete event simulation and utilizing the configuration of the QoS support.

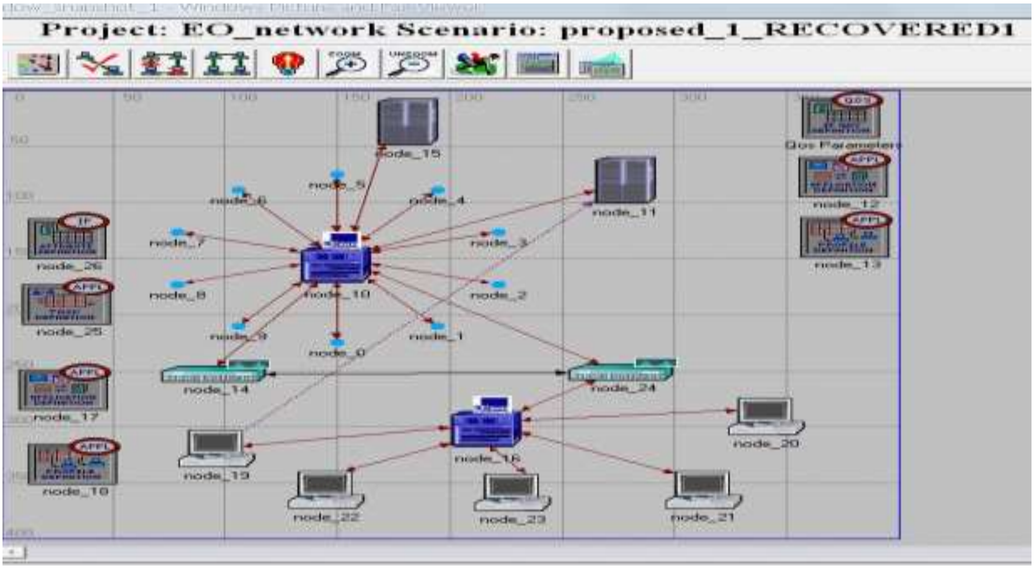



Figure 3. Simulation Testbed for Qpm Model

It was configured to mimic 60 minutes of network activities. Figure 4a & 4b shows the simulation speed and completed snap shot capture of the simulation runs. Figure 5 shows the result of the simulation runs in which QoS parameter such as delay (sec) graph plot was displayed.

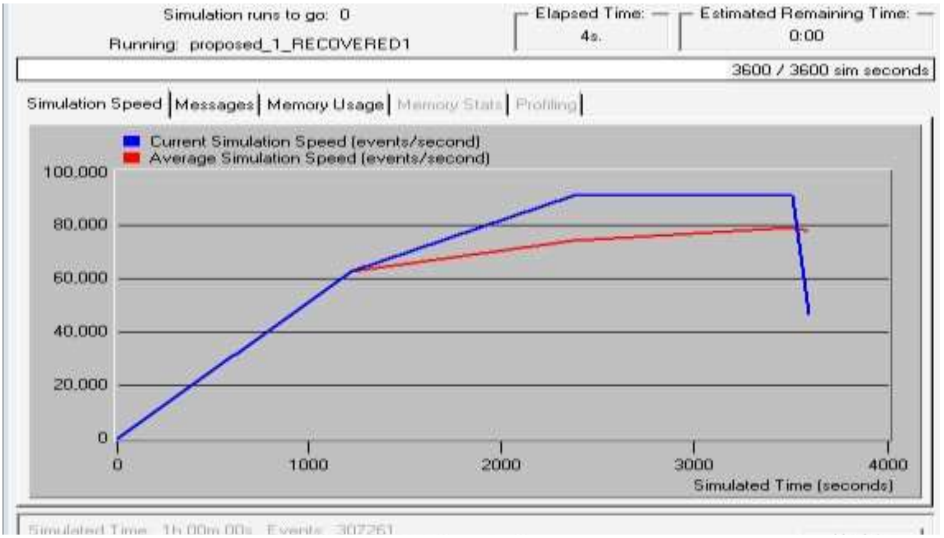



Figure 4a. Simulation Runs (Simulation Speed)

**5. Result and ANALYSIS**

Regarding the summary of the results, it is pertinent to say that the simulated results generated have no doubt validated the QPM model. As we can see the overall delay in the network was approximately in Nano seconds thereby controlling congestion and QoS support in the industrial automation network. Also the model helps to maintain appreciable throughput and guaranteed bandwidth throughout the network activities and industrial automated processes. For better understanding based on the results obtained the analysis and comparisons have been summarized as depicted in Table 1. This provides a list of key benefits of congestion control and QoS parameters relevant to an industrial automation networks by leveraging QPM Model.

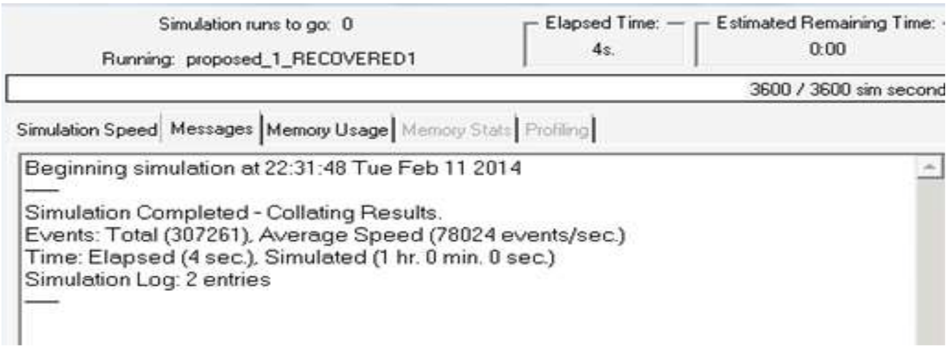
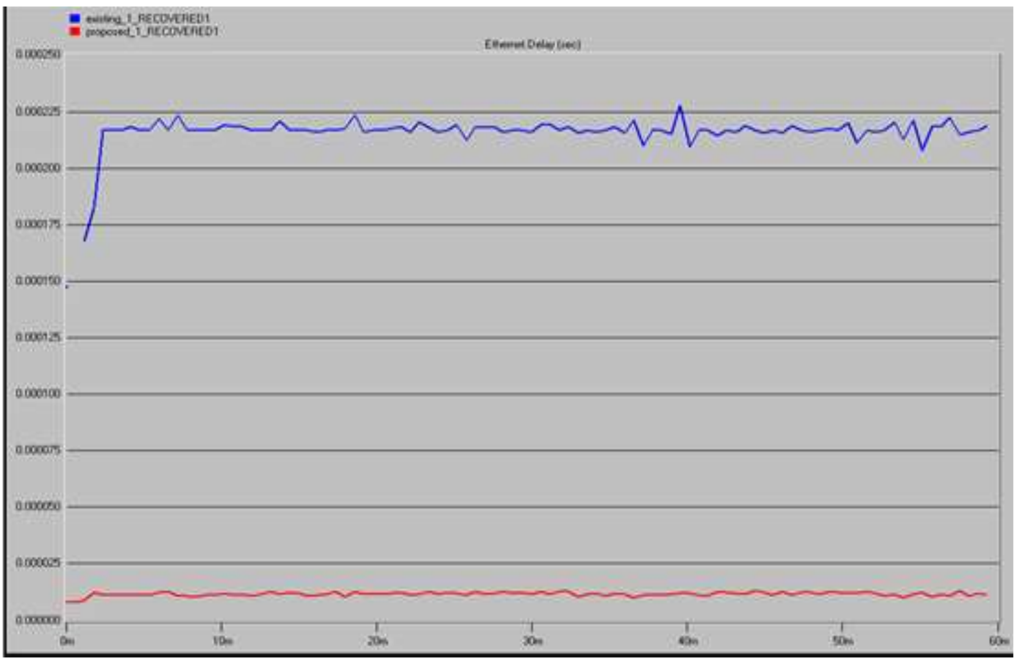



Figure 4b Simulation Runs (Simulation Completed)

Figure 5. Simulation Results Comparison for Ethernet Delay




Summary/Comparison Of Existing Traditional Network and Qpm Model

| Feature/Benefits | traditional network | QPM Model |
|---|---|---|
| Guaranteed Bandwidth/Throughput Support | No | Yes |
| Low end-to-end, and Latency/delay | >10 micro seconds end-to-end.<br>> hundreds of seconds delay | < micro seconds end-to-end.<br>Approximately in Nano-seconds delay. |
| Eliminate retries and timeouts in the transmission | No (Congestion control based on TCP packet only). | Yes (Congestion control optimized with QPM) |
| Deterministic performance | No (QoS and congestion Management is based on dropping of packets. Link control is not class or flow based). | Yes (Granular, class-based link level flow control). |
| Fast deterministic transport performance | No (TCP transport is in conventional software, uses large window sizes, and therefore longer response times for handling congestion. | Yes (Congestion is handled proactively and adaptively through the use of QPM model implemented in the server. Hence shorter response time). |

## 6. Conclusion and Future Works

The QPM model incorporates several novel QoS and Congestion control mechanism that are tailored perfectly to address poor QoS in an Industrial Automation network. It was discovered that the model shows better performance throughput, service availability with lesser delay, network latency and response time. Hence this work has achieved network QoS requirement and as a result makes connectivity and operations in an industrial automation network to be carried out seamlessly in timely manner thereby contributing immensely to efficient productivity in the industries. Furthermore, integrating this model in an Enterprise Composite NOC model and utilizing Differentiated Service Client-Server architecture provides congestion free network, network QoS assurance and eliminates the problems and bottleneck associated with the existing conventional traditional network design in industrial automation network architecture.

Furthermore, optimization of industrial automation network in the approach of a novel network congestion control called QPM has been considered in this paper. The potential to improve the industrial automation network for efficient productivity can be investigated further in the perspective of industrial internet of things (IIoT) in our future work.

## Acknowledgment

Thanks to Gilead Global System Technologies Ltd (GGSTL) for the provision OPNET IT Guru software and facility for the simulation testbed setup.

**References**


Bonald, T. May, M. and Bolot, J. C. (2000). Analytic Evaluation of RED performance. IEEE INFOCOM 2000.

Bongkyo, M. Arhvami, H. (2003). DiffServ extensions for QoS Provisioning in IP mobility environments, in IEEE Wireless Communications, pp.38- 44.

Brakmo, L.S. O'Malley, S. W. and Peterson, L. L. (1994). TCP Vegas: New techniques for congestion detection and avoidance, in Proc. ACM Sigcomm.

Chen, J.C., McAuley, A., Sarangan,V., Baba,S., & Ohba, Y. (2002). Dynamic Service Negotiation Protocol (DSNP) and Wireless DiffServ, ICC'02, New York city.

Crawley, E., Nair, R., Rajagopalan, B., Sandick, H. (1998). A Framework for QoS-based Routing in the Internet. RFC 2386.

Cristianodi, F. (2008). Seminar on transport of multimedia streams over the wireless internet. University of Helsinki.

Ethernet-to-the factory 1.2 Design implementation guide, in: www.cisco.com/c/us/td/docs/solutios/Verticals/EttF/EttFDIG.html. Accessed July 24, 2014.

Henderson, T. R., Sahouria, E., Mccanne, S., Katz, R. H., and Katz, Y. H. (1997). Improving the fairness of TCP congestion avoidance. In IEEE Globecomm conference, pp. 539–544.

Jacobson. (1998). Congestion Avoidance and Control. In Proceedings of ACM SIGCOMM Symposium, (pp 314– 329) IEEE..

Katabi, D., Handley, M., and Rohrs, C. (2002). Congestion control for high bandwidth delay product networks. SIGCOMM Comput. Commun. Rev. 32, pp.89–102. IEEE.

Lakshman, T. V., & Madhow, U. (2005). The performance of TCP/IP for networks with high bandwidth-delay products and random loss. IEEE/ACM transactions on networking, 5(3), 336-350.

Nandita, D. Masayoshi, K., Zhang-Shen, R. & McKeown, N. (2005). Processor Sharing Flows in the Internet. In IW QoS.

Wainer, G. and Rodrigo, C. (2011). DEMES: A Discrete-Event methodology for Modeling and Simulation of Embedded Systems. SCS M&S Magazine – 2011 / n2 (April).

Yee-Ting, L., Douglas, L. & Robert, N. S. (2007). Experimental evaluation of TCP protocols for high-speed networks. IEEE/ACM Trans. Network, 15(5):1109–1122.