Mitigating the Effect of Latency Constraints on Industrial Process Control Monitoring Over Wireless Using Predictive Approach

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Abstract: **This paper presents mitigating the effect of latency constraints on industrial process control monitoring over wireless using predictive approach. The study reviewed many literatures on the challenges of quality communication services in control system industries and identified latency as the major constraint which is caused by the behaviors of Remote Telemetry Unit (RTU) and Programmable Logic Controller (PLC). The system was implemented with neural network toolbox in Mathlab and then simulated. The result showed real time data monitoring performance of 22.05ms which is very good and within the in ISA100.11a, IEC 61850 and IEEEE 802.15 standards for industrial communication systems.**

Keywords: **PMU, RTU, Real time, PLC, ISA100.11a, IEC 61850 and IEEEE 802.15**

I. INTRODUCTION

Industrial communication system (ICS) has dominated the industrial sector over the years, with the aim of ensuring interoperability between industrials plants, machines, computers, etc autonomously to achieve a process called industrial automation [1]. This has today remained an integral part of process design and control systems network. Basically there are two types of ICS which are the wired or wireless [2].

The wired based ICS uses network cables to connect the various process design equipments via surface or conduit wiring. This type of ICS have advantages such as low latency, immune to some environmental problems like as temperature and weather, closeness between process design, communication and control system, cheap to implement among other advantages; however, it also suffers certain limitations such as short circuit connection, accidental disconnection of cables, and corroded terminal due to environmental contamination among others.

Secondly, the use of wired communication systems are limited to only local area industrial network settings and cannot be deployed for the monitoring of remote off shore (off field or remote areas) based plants and machines as required in the oil and gas, power system, among other modern day industrials settings which requires long range remote monitoring of offshore plants, substations, oil rigs etc.

To solve this problem, the wireless communication systems was introduced into the control system architecture, using more advanced system like the wireless sensor network, remote telemetry unit, phasor measurement unit among other transducers which has the capacity to remotely collect data from plants offshore and then transmit via communication bus to the monitoring centers for analysis [3, 4, 5, 6]. This wireless based ICSwas able to improve the monitoring and supervisory performance of industrial control system.

These ICS systems are equipped with wireless based transmitters and receivers which have the capacity to communicate with each other and achieve perfect data interaction and monitoring performance. However, due to distance between the plants and then monitoring centers in some cases, environmental factors such as temperature and harsh weather in the certain plant locations like the oil well, mining field, substation sites among others, the performance of this wireless based ICS are yet to provide the required potential expected for industry 4.0 [7]. These factors have resulted to various technical problems such as latency, losses, interference, etc on the quality of industrial communication performance and most especially do not guarantee real time monitoring which is very vital for reliable data analysis and decision making in the control system industry [8, 9, 10].

Over the years, the need to achieve real time monitoring in wireless based industrial communication and control system have remained a topic for discussion as despite the success achieved so far, the aim of real time monitoring is yet to be actualized.

Real time monitoring performance have been affected over the years by many problems ranging from the communication setup limitations, environmental factors, poor performance of control devices such as programmable logic controllers or proportional integral derivative (PID) controller often used. These control systems are embedded into the transducers aforementioned to process data before transmission to the control center via the communication bus, however the delay response time, delay processing time, issues of overshoot, among other limitations of these control system devices all contributes to the poor quality and delay of data collection in the monitoring center, thus resulting to unreliability of data collected as it is not synchronized with real time [11, 12]. This has problem has remained a major challenges in the monitoring and analysis of technical process performance.

This research proposed to address this problem, using a time series based model predictive controller. This controller is a type which has the ability to approximate time series behaviors of plants and actuators, then sends timely data to the communication bus for transmission to the monitoring unit. This timely approximation of plant behavior has the potential to greatly improve latency performance of the data transmission and hence achieve reliable data analysis.

II. REVIEW OF RELATED WORKS

The section presents the review of related works by various authors, discussing their contribution to knowledge and limitations as shown in the table 1:

Table 1: Review of Relevant Literatures

Author	Title	Work done	Contribution/Limitation
Lutz (2018) [7]	Methods for a reliable wireless communication in the industries	The study took a survey of the various methods to achieve wireless communication in the industrial environment.	The study revealed that environmental factors of industrial applications an distance from the control centers all induces latency and affect real time performance in industries
Jianping et al. (2018) [8]	Challenges of wireless control system in process industries	The study analyzed the challenges in the application of control over technical process wireless sensor networks.	The study shows that the main application of wireless communication in industry is for monitoring purposes only, but identified the sensor network as the long term challenges.
Xiaolin (2018) [2]	Wireless communication network for Time critical Industrial applications	The study revealed that unlike the mobile communications, industrial communication suffers problem of latency and has remained a problem for time critical infrastructural applications.	The study revealed that the overview of physical layer structure is capable of reducing packet latency.
Mark (2020) [9]	Low latency Network for control system application	The study analyzed the impact of latency on closed loop control systems.	The study identified frequency response, system update, bandwidth requirements, network types and topology and latency as control system parameters which must be examined to improve latency performance in industrial communication system
Weiner et al. (2014) [10]	Low latency, high reliability in wireless communication systems for control applications.	The study evaluated industrial control system wireless network architectures	The use of multiple distributive access points to reduce latency in Industrial control system. The use of efficient error control decoders and hardware system are also vital to achieve reliability in industrial communication and automation efficiency.
Yilmaz et al. (2015) [11]	Analysis of ultra reliable and low latency 5G communication for factory automation use case	The study discussed the requirements and challenges of orthogonal frequency division multiplexing based 5G radio interface for critical machine type communication. The impact of low latency ultra modern system as a solution to latency in industrial automation was also analyzed.	The study evaluated the system level performance carried out at different industrial scenarios and the result shows that there is still great room for improvement despite the success.
Luvisotto et al. (2017) [12]	Physical layer design of high performance wireless transmission for critical control application	The study emphasized on the need to extreme low latency, high data rate and reliable wireless communication systems to improve control system automation performance. The research proposed a bottom up approach which improved quality of communication service in control system automation and allow substantial reduction of latency based on the IEEE 802.11 standard.	The result study still gives room for improvement to further minimize latency.
Marko and Kauko (2010) [13]	Wireless sensor network (WSN) in industrial automation	The study reviewed the various protocol and industrial in industrial wireless sensor network. the research also identified problem of interference from the industrial environment among the probe which affects communication performance of WSN	The study identified various communication constraints such as network delay, frame time delay, waiting time delay, propagation delay, packet drop out, network delay which are issues for WSN automations

III. LATENCY: A CONSTRAINT FOR END TO END COMMUNICAITON

In the present day industrial control system network settings which wireless communication are an integral part for remote monitoring, standards such as the ISA100.11a, IEC 61850 and IEEEE 802.15 are employ as methodology to design the architecture [14, 15, 16]. These standards specified maximum latency range from 100ms to about 2000ms as the suitable delay communication time for process automation [2]. The process design systems like the wireless interface for sensor and actuator which are developed to support wireless data exchange at a transmission rate of 1Mbit/s and latency is 2ms, have been presented in [17, 18]. However, the technical challenges associated with wireless sensors, limitation of processing controller have remained the major actor which contributes to latency and as a result never allowed the realization of real time monitoring.This problem is proposed to be addressed in the net section.

3.1 Causes of Latency in ICS

Having identified latency as a major problem to achieve real time monitoring in industrial communication network, there are some elements which are the major causes. Taking a look at the basic process control system network wirelessly interconnected in [8], it was observed that the communication standard for industrial internet has the potential for real time communication as the parameters which causes latency such as congestion, large packet size, among others are not always the case for industrial internet, based on the fact that the relative size of packet transmitted by ICS are very small compared to mobile communication system which are designed to transmit more, it is strange that the level of latency in ICS is always greater than that of the mobile communication system.the two main causes of latency in the ICS are the limitations in Wireless sensor elements like the Remote Telemetry Unit (RTU) and also the logic solver which is the processor.

i. Remote Telemetry Unit (RTU)

According to [19, 20, 21] some of the system like the Remote Telemetry Unit (RTU) for instance which is one of the most employed elements in process design do not collect data in real time. RTU are used mainly due to their rugged nature to withstand harsh environment and weather conditions are mostly used for monitoring in remote locations, but is suffers inability to provide real time behavior of the system.

ii. Logic Solver

According to [22] the Programmable Logic Controller (PLC) has dominated the global industrial process design and control settings. This PLC has many advantages such as compatibility in various industrial automation sections, ability to perform multi control operations, low cost when compared to some controllers among others, however the limitation of this PLC includes delay processing and response time, overshoot, aggressiveness [22, 23], and most importantly is intelligent but lacks common sense (the operate based on settings and not machine learning intelligence). Despite the merits of the PLC, these aforementioned limitations have hindered their reliability as a real time processing system, thus increases latency in ICS.

IV. PROPOSED SOLUTION

The solutions to these problems are vital to achieve real time or near real time based on the ISA, IEC standards for ICS. Proposing the development of a new controller entirely can be very expensive and time consuming to implement in the global industrial process design architectures as the PLC have dominated the market and already configured with the process design. However this PLC can be made to more intelligence using Artificial Neural Network (ANN) which was identified by [24] as set of biological neurons with the ability to learn from training dataset patterns and then make accurate decisions. The ANN according to research by [25]has the ability to make Time Series Approximations (TSA). This TSA is the ability to accurate make predictions of the plant behavior and then immediately send to the control center. This predictive model was already developed by the researcher in [25], but in this case is proposed to be used to improve the performance of the PLC. This process involves training the ANN to develop a predictive model and then deployed into the PLC controller as recommended by [24] as a tuning process to improve PLC. This enables the PLC to have time series based intelligence of the plant behavior. In the case of the sensors, the phasor measurement unit which has the ability to collect data in synchronized Global Positioning Satellite (GPS) time is preferred ahead of the RTU as identified in [25] and then coupled with the improved PLC predictive controller will ensure that data are collected and transmitted in approximate real time to the monitoring center. The proposed block diagram of the improved monitoring system is presented in figure 1;

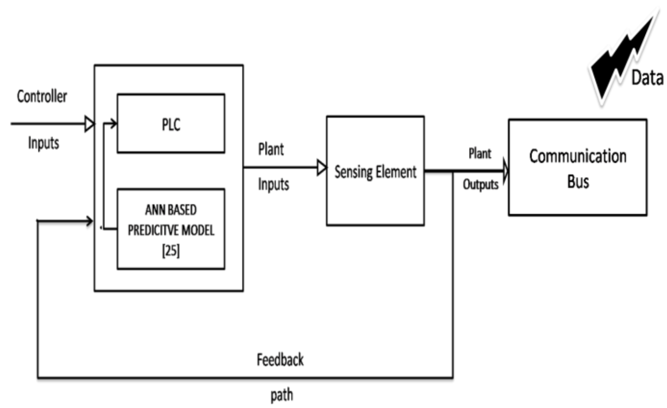

Figure 1: proposed system

The figure 1 presented a closed loop based predictive monitoring system for real time data collection, processing and transmission. The ANN predictive model was use to improve the PLC performance and then optimize the data collection process and send to the communication bus to transmit to the monitoring center.

V. THE SYSTEM IMPLEMENTATION

The system was implemented using simulink via neural network toolbox. Data of the plant was collected and used to training neural network configured in the tool to generate the reference model used to enhance the data collected and supervisory control performance of the PLC. The simulink model of the neural network training tool is presented in figure 2;

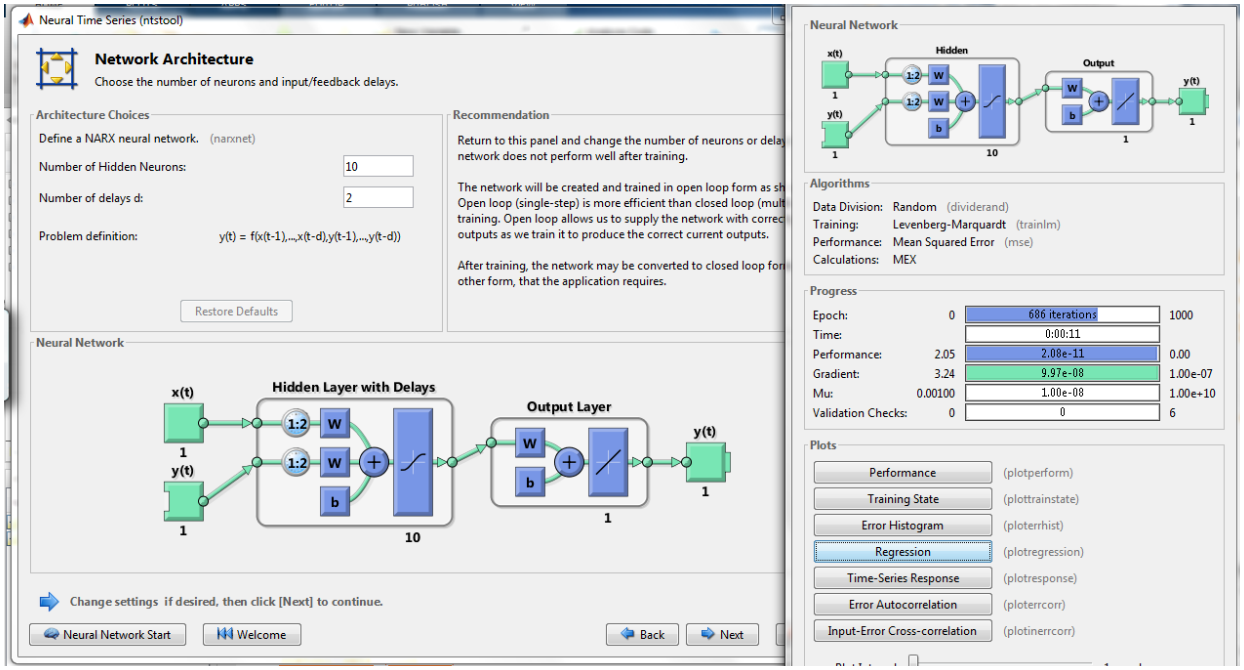

Figure 2: the neural network training tool

The figure 2 presented the neural network training tool configured with the training parameter in the table 1; the tool was automatically divides the data into three ratios for test, train and validation before the training commences. The aim was to training and then ensures that the training and learning process is reliable.

Table 1: Simulation parameters

Parameters	Values
Size of hidden layer	10
Training epoch	700
Controller training segment	100
No. delayed reference inputs	2
Maximum feature outputs	3.1
Number of non hidden layers	2
Maximum interval per seconds	2
No. delayed outputs	1
No. delayed feature output	2
Minimum reference value	-0.7
Maximum reference value	0.7

The performance was examined using the response time graph in figure 3;

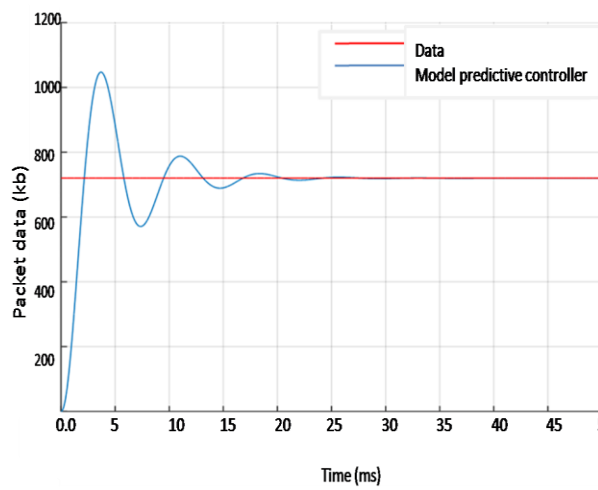

Figure 3: The Step response of the new RTOC system

The figure 3 presented the response time of the neural network controller used to improve the conventional data processors (PLC and RTU). The result showed that the neural network improved system was able to detect and transmit data collected at 22.05ms which is very good based on the specification of the ISA100.11a, IEC 61850 and IEEEE 802.15 standards for industrial communication systems. To measure the system reliability error analysis of the training process was performed using Mean Square Error (MSE) analyzer as shown in the figure 4;

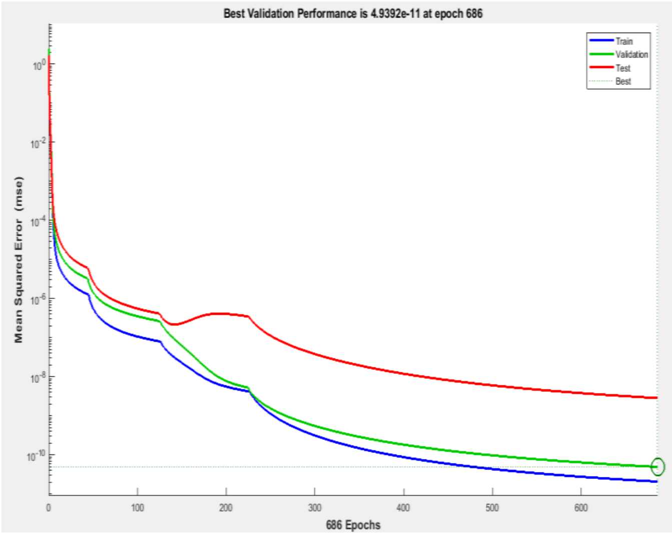

Figure 4: Error performance of the system

The aim here is to achieve an error value of equal or approximately zero. From the result in figure 4 the error of the neural network was measured to determine the rate of the system unreliability. From the result it was observed that the MSE result is $4.9322e^{-11}$Mu which is very good as it is approximately zero. The implication of this result showed that the neural network was able to improve the processing performance of the PLC and RTU and achieved better data collection and process supervision.

VI. CONCLUSION

In [25] the researcher already developed a neural network based predictive model to replace the conventional PLC controller in the ICS settings, however [24] revealed that PLC have dominated over 98% of global industrial process design and control architectures and hence replacing all will be time, consuming, cumbersome and cost effective. This study therefore adopted the already ANN based predictive model and improve the performance of PLC as proposed in [24] which identified the limitation of PLC. This was used to make the PLC have predictive intelligence and have accurate time series understanding of the plant behavior. Furthermore the use of PMU was employed in place of the conventional RTU, to optimize data collection performance with GPS time synchronization. This was used to improve the monitoring performance of the wireless based ICS and satisfy the requirements in [15, 16] for reliable process automation performance.

VII. CONTRIBUTION TO KNOWLEDGE

i. Systematic review was done which revealed that latency remained the main problem to the realization of real time monitoring according to the requirements for [15, 16]

ii. An improved predictive PLC was proposed to improve the monitoring performance of Industrial communication system.

VIII. RECOMMENDATION

Having completed this research, the following are recommended;

i. The use of RTU should be replaced with PMU for better real time data collection

ii. The proposed system should be used to improve the conventional ICS and process design settings

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