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Multilevel Data Acquisition for Intelligent Control in Wireless Sensor Network

[1]V.Vijayakumar, [2]S.Punitha, [3]X.Thomas Britto
[1]Assistant Professor, [2]Assistant Professor, [3]Assistant Professor, Electrical and Electronics Engineering, N.S.N College of Engineering and Technology, Karur, India

Abstract: This paper proposes a novel approach for Structural health condition monitoring based on Neuro-Fuzzy systems (NFS). This can be done effectively by multilevel data acquisition process in Wireless Sensor Network (WSN). This is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer. From that process identification of system anomalies and faults can be done easily. In standard control systems these abnormalities can be observed as gradually deviating trends from the normal behavior. Tools that are available for monitoring these trends, in some cases may not be enough to reveal hidden faulty features. For interpreting these changes accurately, measured data values must be visualized as a combination of multiple sensor signals within a particular domain. In this paper an approach to effectively utilize integrated data from multiple sources, and defines a set of fault features is given. The approach confidence values are set based on these interpretations to differentiate normal and abnormal conditions exhibited by the operating system. This is to provide an opportunity for the process and maintenance engineers to effectively identify the equipments health based on the early identification of developing abnormalities.
Keywords: Structural health monitoring, multilevel data acquisition, WSN, Neuro-Fuzzy system

I. INTRODUCTION

Nowadays sensor networks have gained much importance in many practical applications [1]-[3] investigate specific sensor networks for aircraft structural health and performance monitoring. A highway bridge assessment using an adaptive real-time sensor network is proposed in [4]. A real-time radiological area monitoring sensor network is developed in [5] for emergency response. A congestion-aware, loss-resilient bio monitoring sensor network is reported in [6] for mobile health applications in the medical field. A novel interstitial fluid sensor network is provided in [7], [8] for remote continuous alcohol monitoring. [9] uses an energy efficient wireless sensor network for localization based structural health monitoring. [10] employs a fault-tolerant wireless sensor network for hierarchical aggregation and intelligent monitoring and control. In this paper sensor based intelligent system is proposed and applied for remote oil well structural health monitoring and performance measurement. The main motivation of this paper is to detect exact malfunction in oil well and inform to corresponding maintenance staff. Also improve the overall system accuracy and efficiency. This system has three important levels, first level sensors (FLS), intelligent sensors (IS) and third level sensors (TLS) are used for Data collection, data processing and malfunction detection respectively. During data collection, five sensors are commonly used for an oil well's sensing data, which include a load sensor, current sensor, angular sensor, pressure sensor and voltage sensor for data processing. In existing work, the malfunction can be detected by using an Artificial Neural Network (ANN) method. It has some disadvantages while dealing with complex rate as it consumes much time for processing and less accurate in malfunction detection. To overcome these shortcomings, here using Neuro-Fuzzy system for malfunction detection, that malfunction report to the maintenance staff via Global System for Mobile communications (GSM) and receive Short Message Service (SMS). The remaining paper is organized as follows. Section II introduces the whole system description. The development of IS is given in Section III. The development of the TLS is in Section IV .The simulation results are given in section V, and followed by conclusion in Section VI.

II. SYSTEM DESCRIPTION

The system having three level of sensor process (i) First level sensor (ii) Intelligent Sensor (iii) Third level sensor. In our proposed system FLS consists of a load sensor, an angular sensor, a current sensor and an oil pressure sensor while the IS mainly contains two components: the designed control board and the frequency converter. Five kinds of sensing data from FLS are imported to its IS. The IS usually transmits oil well static parameters, significant malfunction reports, dynamic sensing data and elementary processing data directly to the TLS. As a special case, when the wireless communication between the IS and the TLS fails, the IS sends data to its adjacent for relay transmission up to the TLS.

On the other hand, when acquiring a pumping stroke adjustment command from the TLS, the control board executes this command by transporting the corresponding control logic down to the frequency converter, which has the capability of changing power frequency as well as the OPU's pumping stroke. Malfunction can be detected by using neuro-fuzzy system and that can be informed to the corresponding staff via GSM.

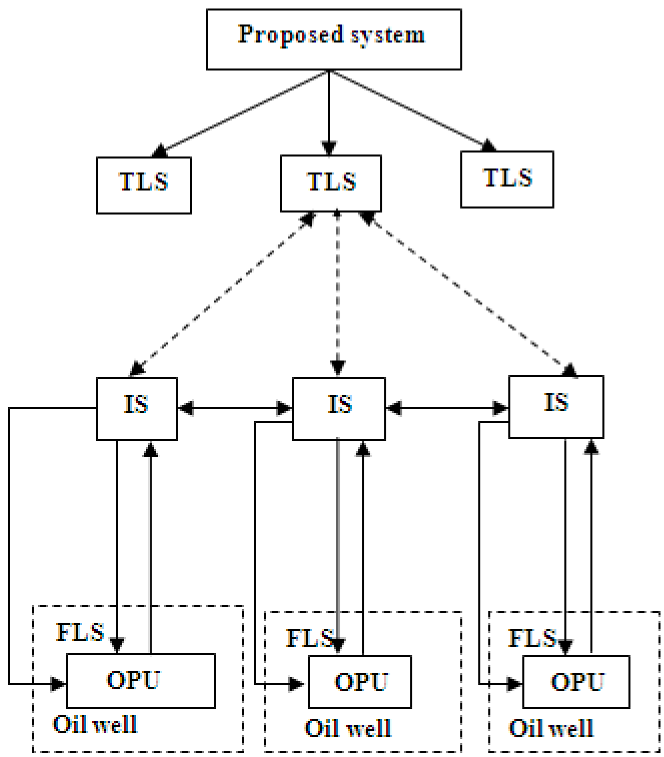

Fig 1. System Topology For Opu Health Monitoring And Intelligent Control.

III. DESIGN OF IS

IS consists of the following six modules: a central processing unit (CPU), a sensing module, a module for relay protection, frequency converter and wireless communication and a user interface module, which are given a detailed introduction in the following paragraph

1) *CPU Module:* The CPU has 20 Inputs/Outputs (I/O), 8 A/D converters, 8 D/A converters, 8 Keyboard interface, a LCD interface. It also has an external clock module so that the clock information may not be lost even though its power is suddenly cutoff. All other five modules are connected to the CPU. All data from the other four modules except for the frequency converter module is imported to the CPU before making a decision. The stroke adjustment command coming from TLS is also translated by the CPU and then sent out to the frequency converter module.
2) *Sensing Module:* Sensing module contains a load sensor, an singular sensor, a voltage sensor, a current sensor, an oil pressure sensor and a conditioning circuit. The load sensor is employed to acquire instantaneous load of slick rod. The angular sensor is used for measuring the instantaneous inclination of OPU crossbeam. The voltage sensor and the current sensor are to measure the instantaneous voltage and the current of power supply. The sensor for oil pressure is used to measure the oil pressure of the oil pipe.
3) *Relay Protection Module:* Relay protection module consists of a circuit breaker, a contactor and a connection circuit. This module is used for detecting the motor operation by analyzing sensing data from the current sensor and the voltage sensor. Whenever a malfunction, such as a short circuit, a phase missing or an over current, occurs on the motor power, relay protection module will immediately cut off the power supply.

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4) *Interface Module:* This module is the interface between staff and IS, by which OPU can be started or stopped, the stroke of OPU can be changed, OPU parameters can be preset, sensing data can be inquired and the malfunction information can be acquired.
5) *Frequency Converter Module:* Frequency converter module contains frequency converter and a braking resistor. On one hand, this module can realize soft boot for motor, which reduces inrush to OPU and motor. On the other hand, this module can adjust the motor speed according to the received command from CPU so that the stroke of OPU is adjusted and the power is saved.
6) *Wireless Communication Module:* Wireless communication module is made of a radio station and Yagi antenna. 9-pin RS232 serial is utilized for the connection between CPU and radio station. Sensing data and OPU parameters are sent to network center by using this serial and Yagi antenna.

A. Printed Circuit Board of Our Developed Control Board

The proposed IS mainly consists of two components:

1) Our designed control board, which is the core of the whole IS and 2) a frequency converter, which is applied for the power frequency adjustment. Compared to the frequency converter, the control board (PCB), the relay protection module is space-separated from other logic circuits because the voltage goes through the relay protection module while the 20 V DC is used for other logic circuits. Space separation between the relay protection nodule and others avoids interferences.

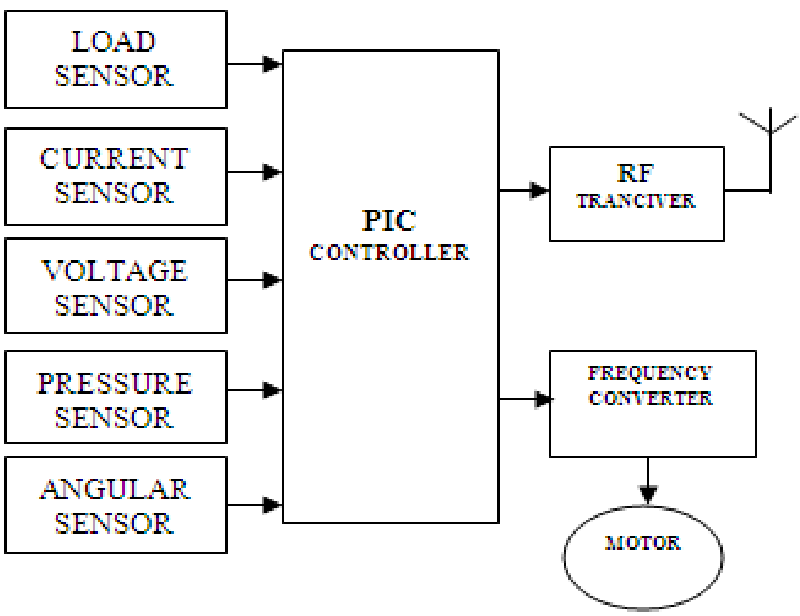

Fig 2. Data Processing in the IS

B. Embedded Software Development of IS

In our proposed IS embedded software development for the CPU contains 4 tasks and 4 interruptions. Four tasks consists of sensing collection of data from FLS, data elementary processing, significant malfunction scan and user interface response. Sensing data collection indicates collecting dynamic sensing data and automatically storing these data in the IS. Data elementary processing means to process the raw sensing data to acquire the required typical data, such as the maximal/minimal/average value, the active /reactive power and the system efficiency, etc... Significant malfunction scan is to detect the severe abnormalities, such as short circuit, missing phase and over current, and report them. Also, the user interface is in charge of the external input, the menu display, the oil well static parameter storage and the static parameter update, where sensing data collection has the highest priority, the next is data elementary processing, which is followed by a significant malfunction scan and the last is the user interface response including interrupts in timer, A/D interruption, interruption in communication and keyboard interruption. Timer interruption is to precisely control sampling rate. A/D interruption guarantees the sampling process. Communication interruption is used for data/command reception from other sensors. Keyboard interruption guarantees that the external input can be responded to in right time.

IV. DESIGN OF TLS

TLS includes three components: 1) a user interface for interaction 2) some embedded algorithms for wireless communication between the TLS and the IS, a regular data request on all managed IS, a malfunction diagnosis, a pumping stroke adjustment and GSM SMS and 3) a database for data storage. The wireless data, usually including dynamic sensing data and significant malfunction reports for one specific OPU, is acquired via the communication protocol and is then stored in its database. After a thorough malfunction detection in the TLS, once a malfunction is identified, it is immediately sent to the maintenance staff via a GSM, which generates a corresponding short message transmission. Furthermore, after a thorough data processing, if one OPU needs a different pumping stroke to improve power efficiency or increase oil production, a pumping stroke adjustment command will be send down to its IS, by which the corresponding OPU's pumping stroke can be changed. For instance, in barren oilfield, with a high pumping stroke for a couple of hours, the oil level goes down and the oil production thus decreases too even with the same pumping stroke. At this time, a lower pumping stroke should be used for power efficiency. Therefore, the command to decrease its OPU pumping stroke is transmitted down to its IS. As mentioned above, this command is executed via the frequency converter.

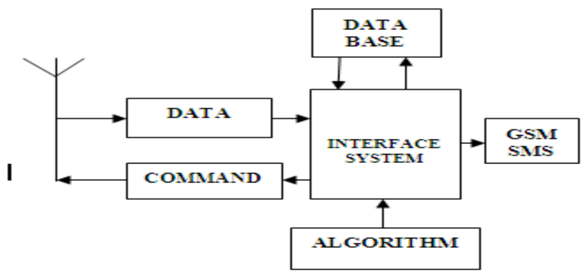

Fig 3. System Description of the TLS.

A. *Design of User Interface*

1) The user interface of the TLS has several sub-stages:

Dynamic indication of per OPU current typical data, current and current malfunction-diagnosis results; 2) Query of per OPU historical data, historical typical data, historical LPD, historical pump diagram and historical malfunction- diagnosis reports; 3) Forms for reporting statistics; 4) OPU's pumping stroke adjustment; 5) Data communication (Data transmission request on a typical OPU) and GSMSMS. This interface is directly developed using Borland Delphi. The various data-processing algorithms and data transmission/reception protocols behind this interface are introduced

B. *Wireless communication between TLS and IS*

1) Communication Frame Types : In the wireless communication between the TLS and the IS, there are two types of frames: the command frame from the TLS to the IS and the data frame from the Is to the TLS/IS. As shown in Fig. 4(a) the command frame from the TLS contains five parts: frame head, address, command, additional information and checksum, where the frame head is used as a sign of TLS command arrival; the address is a unique number for per OPU, i.e., the oilwell number; the command possibly indicates 1) clock synchronization 2) pumping stroke adjustment 3) OPU data request or 4) OPU significant malfunction request, additional information means the command content (if necessary) and the checksum is used for checking the transmission integrity. On the other hand, as shown in fig 4(b) the data from the IS to the TLS/IS contains four parts: frame head, address, data and checksum, where the frame head is used as a sign of the IS data arrival; the address denotes a unique number for the TLS or for another OPU; the data indicates the response fro each command frame 1) Yes or NO for clock synchronization command and pumping stroke adjustment command 2) sensing data for data-request command and 3) fault name for TLS significant malfunction request command and the checksum is once again is used for checking the transmission integrity.

Frame head	Address	Command	Additional information	Check sum

Fig 4(a). Command Frame from TLS

Frame head	Address	Data	Check sum

Fig 4(b). Data Frame from IS

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2) *Data Communication between TLS and IS:* The data communication process between TLS and IS illustrates the process of TLS data request on a specific OPU.TLS continuously sends the command of data request for a specific OPU within the allotted time if it does not acquire the corresponding IS ACK signal. Once the prescribed time is out, the data request process fails. Usually, within the allotted time, TLS can get an IS ACK signa, then read its COM1 ports for data reception and sends an ACK signal to this IS. On the other hand, each IS continuously detects its COM1 port to see any TLS command or any IS relay request. Once acquiring a TLS data request, the IS firstly sends sensing data directly to the TLS and then awaits for a TLSACK. Usually, it gets a TLS ACK and completes the data transmission process. In some cases, a TLS ACK is not acquired and then it sends sensing data to its adjacent IS for relay transmission to the TLS. Alternatively, once acquiring a relay request, this IS will directly transmit the received data to the TLS and complete the data transmission process.

V. MALFUNCTION DIAGNOSIS

This project considers the 7 most important oilwell malfunctions, (1) underground oil shortage, (2) gas effect, (3) moderate load, (4) normal load, (5) idle load, (6) plunger stuck, and (7) oil pump serious leakage malfunction. There are many methods of rule generation. However, most of the rules obtained by these perception based approach, when applied in neuro-fuzzy systems for classification, result in some misclassifications. The perception-based approach, method generates fuzzy IF-THEN rules, from a data set, by use of fuzzy granulation. The neuro-fuzzy systems, which utilize these rules, perform without misclassifications.

A. Fuzzy logic and neural networks are natural complementary tools in building specific intelligent modules or systems. While neural networks in this context are low-level computational structures that perform well when dealing with actual raw data, fuzzy logic comprises of reasoning on a higher level, using linguistic information acquired from domain experts. However, fuzzy systems lack the ability to learn and cannot adjusts themselves to a new environment. On the other hand, although neural networks can learn, they are opaque to the user

B. Integrated Neuro-fuzzy systems can combine the parallel computation and learning abilities of neural networks with the human-like knowledge representation and explanation abilities of fuzzy systems. And as a result, neural networks become more transparent, while fuzzy systems become capable of learning.

C. A Neuro-fuzzy system is a neural network which is functionally equivalent to a fuzzy interface model. It can be trained to develop IF-THEN fuzzy rules and determine membership functions for input and output variables of the module. Expert knowledge can be included into the structure of the Neuro-Fuzzy system. At the same time, the connectionist structure avoids fuzzy inference, which results in substantial computational burden.

D. The structure of a Neuro-Fuzzy system is similar to a multi-layer neural network. In common, a Neuro-fuzzy system has input an output layers, and three hidden layers that denotes membership functions and fuzzy rules.

E. When a representative set of examples is available, Neuro-Fuzzy systems can automatically transform it into a robust set of fuzzy IF-THEN rules, and thereby decrease our dependence on expert knowledge when building intelligent systems.

VI. SIMULATION RESULTS

In the malfunction detection process the following malfunctions are detected and simulated, (1) undergroung oil shortage, (2) gas effect, (3) moderate load, (4) normal load, (5) idle load, (6) plunger stuck, and (7) oil pump serious leakage. Some of the simulation results are given below

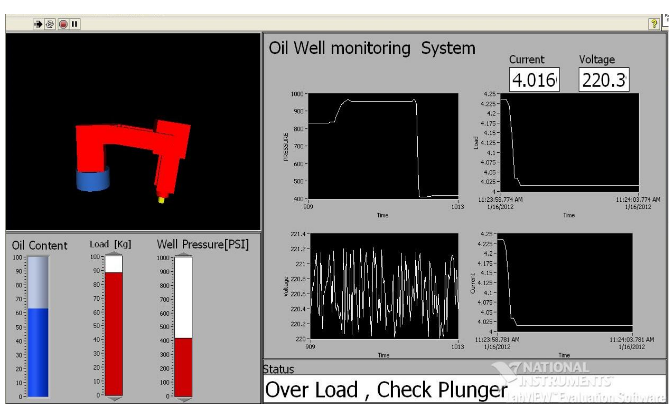

Fig 5(a). Plunger Stuck Malfunction

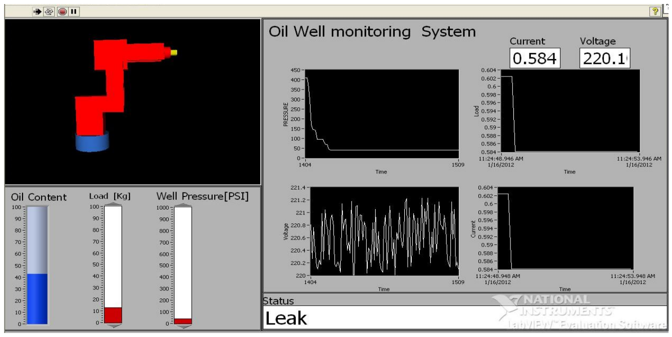

Fig 5(b). Oil Pump Serious Leakage Malfunction

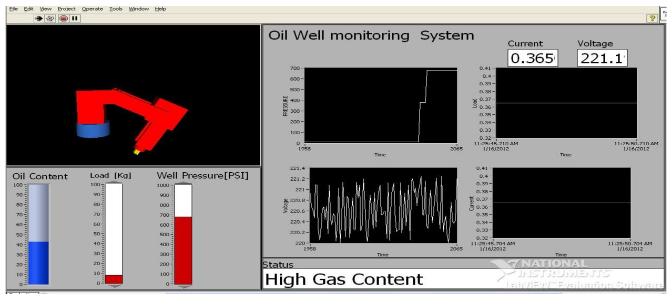

Fig 5(c). Gas Effect

VII. CONCLUSION

This paper reflected the use for a Neuro-Fuzzy system (NFS) approach to model highly complex non-linear data from an offshore. The fuzzy neural networks can learn and extract useful information from input data, ultimately transforming it into useful information about the system condition. These indicators can play a vital role in reducing uncertainties associated with the events. The work on defining framework for wireless sensor network that monitors and controls the offshore oil well healthiness is simulated. The results of the simulated model are in line with the conceptual model. The proposed work has multiple advantages for the user in terms of flexibility, accuracy and comfort. The neuro fuzzy based decision system applied on a distributed data acquisition and control system makes it suitable for multiple large scale structural monitoring system. The results are encouraging and future work involves the design of an appropriate hardware test bed to evaluate the result in real time

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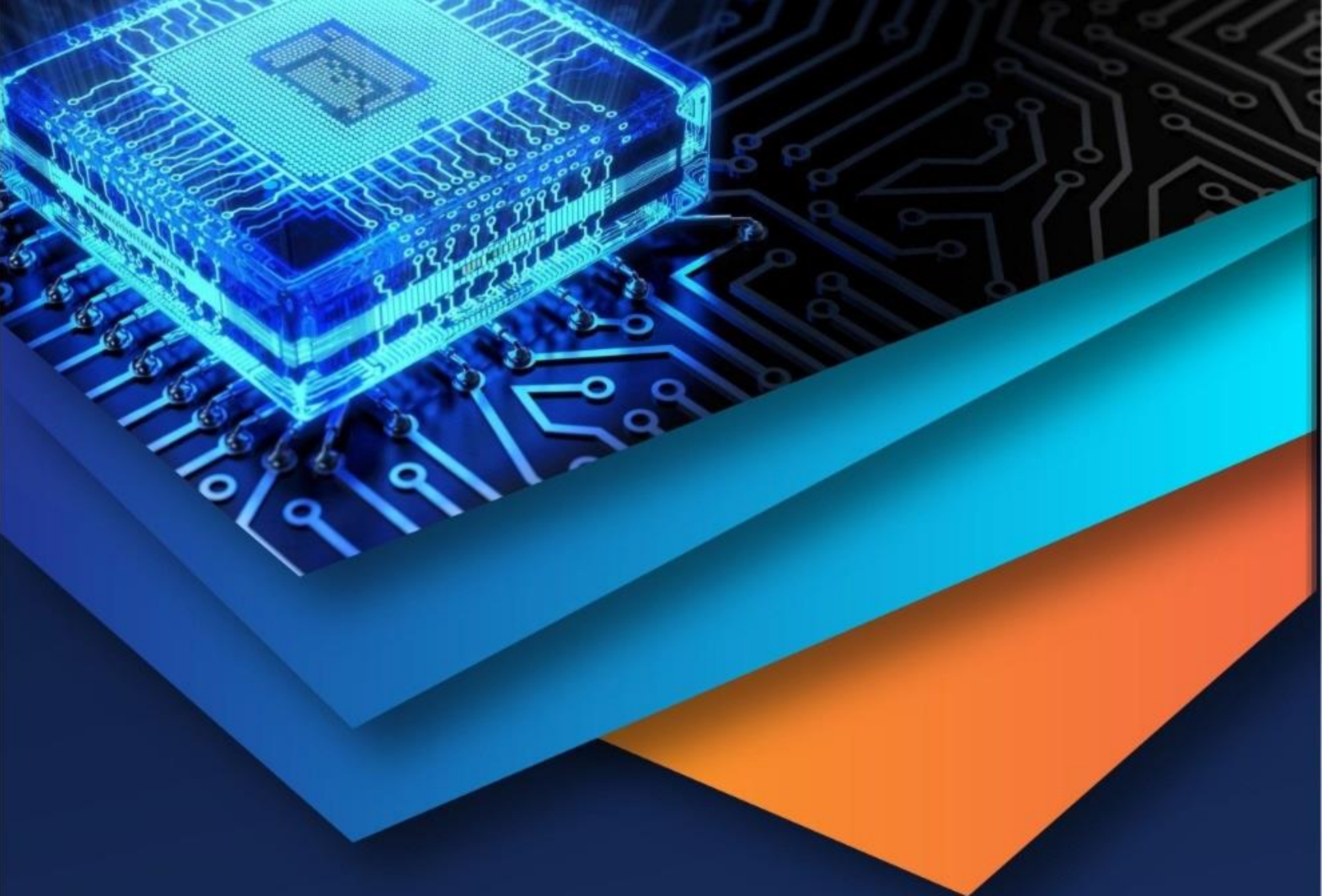

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