Journal of IoT in Social, Mobile, Analytics, and Cloud (ISSN: 2582-1369)
www.irojournals.com/iroismac/

An Effective Approach of IIoT for Anomaly Detection Using Unsupervised Machine Learning Approach

Umesh W. Hore[1], D. G. Wakde[2]

[1,2]Department of Electronics and Telecommunication Engineering, P.R.Pote College of Engineering & Management, SGBAU, Amravati, Maharashtra, India

E-mail: [1]umeshhore@gmail.com, [2]dr_wakde@rediffmail.com

Abstract

The Industrial Internet of Things (IIoT) has the potential to boost the growth of industrial intelligence, increase production effectiveness, and lower manufacturing costs. The automatic monitoring and identification of anomalous events, changes, and drifts on the acquired data constitutes one of the Industrial IoT's primary objectives. All methods for identifying data patterns that differ from expected behaviour are categorised as anomaly detection methods. Accurately and promptly detecting anomalies is becoming more and more crucial since Industrial IoT device failures have a significant impact on the production of industrial goods. Also, anomalies which are needed to be identified could be used for better data analysis.

So to address these problems, in this paper work is carried out using unsupervised learning with clustering approach in which sensors data from a prototype embedded system are used for findings anomaly in the data and the concept is to recognise clusters for interpretation of sensed data under different working circumstances to evaluate if new inspections fall in to any of these clusters. The approach is to find faulty or normal working conditions based on the anomaly findings methods applied to sensor data for analysis. There are three methods used in this proposed approach include fuzzy c-means-k-means clustering, and density-based clustering. The complete approach is found to be favourable for anomaly finding and situation control using cluster-based methods for industry related equipment's systems rely on sensor data. The experimental results indicates that proposed method is accurate and effective based on sensor for different operating conditions of industrial scenario and assist in predictive maintenance.

Keywords: Unsupervised learning, IIoT, industrial scenario, predictive maintenance

DOI: https://doi.org/10.36548/jismac.2022.3.005
Received: 23.07.2022, received in revised form: 12.08.2022, accepted: 28.08.2022, published: 08.09.2022

1. Introduction

The industrial internet of things (IIoT) refers to the extension and use of the internet of things (IoT) in industrial sectors and applications. IoT often concentrates on user convenience. IIoT, on the other hand, focuses on return on investment (ROI) to ensure that organizations get the most out of implementing IIoT. IoT and IIoT mostly rely on hardware like sensors, internet connectivity, and embedded systems However, IoT is less expensive than IIoT since less precision is needed for IoT devices than for IIoT devices. Due to its application in crucial industries like manufacturing, machinery monitoring, etc., IIoT employs increasingly advanced devices for greater precision. Compared to IoT applications, IIoT applications are more sophisticated. The complexity also grows as a result of technology improvements. IoT applications are simpler than IIoT applications. IoT end requirements are focused on user convenience, while IIoT end requirements are focused on ROI. IoT focuses on controlling home equipment that make consumers' lives more convenient by using less resources, such power. IIoT, on the other hand, focuses on crucial systems including those in the healthcare, aerospace, and manufacturing industries, as well as on automating factory machinery, linking people and machines, and doing data analytics. The IIoT aims for greater uptime and decreased downtime for commercial operations. One of the industries that benefits from anomaly detection solutions is industrial IoT. Industrial Internet of Things applications have used anomaly detection for things like health monitoring, power systems, air conditioning and heating ventilation system fault detection, manufacturing quality control systems, and scheduling production facility maintenance.

The modern technologies like IoT, AI are useful for transformation from reactive maintenance to preventive maintenance & preventive to predictive maintenance. Reactive maintenance paid high cost as compared to predictive maintenance as reactive maintenance are responsible for restoring operating conditions after failure of system so in order to avoid this situations the predictive maintenance is useful for identifying the sound operating conditions of industrial assets and also reduce the frequency of maintenance. [1] Framework for energy optimised approach based on communication & informed data collection is implemented using AI based CRP method. [2] Production & service quality can be improved using tensor base multiple clustering method where method is useful in finding different unknown data structures in big data from different perspectives. [3] IoT have certain issues like topology , maintenance & energy requirements and data aggression which can be addressed using clustering algorithms to provide better solution to these issues. [4] Simple and nonlinear variations of large-scale original input data into higher-level abstract expressions could be improved using reinforcement learning which assist in decision learning process. [5] SoftMax deep neural network is used for reduced latency & communication overhead in which resources are managed in a best way for storage, computing, and bandwidth requirements. [6] Adaptive cluster process are useful in measuring the quality of cluster based on data distribution. [7] Industry 4.0 is a need in today's industrial scenario & time demands it also So Internet of things network consists of huge numbers of objects, things, sensors & devices for providing useful and important services required for healthy environment for industrial operations.

Major focus on IoT is to manage home appliances for consumer convenience assist in reducing resources like electricity. IoT architecture consists of the devices, network structure, and cloud technology that allows IoT devices to communicate with each other whereas IIoT architecture is defined by layers of interaction, including device, communications and semantic. The device layer, architects design how devices interact with communications systems to connect and interconnect in a structure. Whereas communications layer, systems use protocols to exchange actionable information and ssemantic interoperability is a collection of technologies that enable computer systems to interact unambiguously. The proposed experimentation illustrated the design of the IIoT solution, for prototype industrial plant during normal and abnormal situations in industry, analysed with unsupervised machine learning approach by using clustering algorithms and presented the anomaly detection of sensor data analysis to create a smart enterprise based on industrial situations during manufacturing process. The flow of paper is section II is related work then there is information regarding proposed methodology in section III and at last the result discussion & conclusion in section IV & V respectively.

2. Related Work

Supervised learning needs past data and unable to classify new faults so unsupervised approach is useful for known & unknown fault prediction using density estimation via Gaussian Mixture Model Clustering and K-means algorithm. [8, 9] It is need of explainable unsupervised linked through communication & information infrastructure to contribute benefits in terms of ML models in CPSs where huge amounts of unlabelled data is produced to maximised the use of Machine learning in CPSs also useful in predicting unknown faults. [10] Sensor data from operational time in a process tested using unsupervised approach which is useful in predictive maintenance as there is a challenge of predicting certain types of faults of an industrial equipment. [11] For unpredictable faults the unsupervised approach is most effective as compared to supervised & semi supervised as they are used some restrictions in novel cases. This approach is useful to deal with railway operations to detect, identify & predict faults on rail cars to avoid accidents. [12] The emphasis is given to predictive maintenance which is helpful in reducing maintenance cost is adopted in BC Hydro, strategies in keeping generating stations. [13] Early detection of anomalies in CPSs can be detected by unsupervised machine learning of models of the historic system [14] Big data architecture using an unsupervised anomaly detection technique useful for monitoring automated equipment in entertainment industry. [15] Faults of tire & wheel bearing has been identified and used for the study with a clustering approach based on Mixture of Hidden Markov Models. [16] Prediction accuracy for early fault detection can be increased in autoencoder using thermodynamic equation of compressors discharge temperature. [17] Remaining useful life forecasting accuracy significant factor in the equipment maintenance process is addressed using a novel dual mix-up adversarial domain adaptation (DMADA) approach. [18] Maritime industry for enabling smart maintenance is studied using Real-time anomaly Detection Intelligent System architecture consist of Long Short-Term Memory-based Variational Autoencoder. [19] Sensors, wireless transmitters, and gateways faults are needed to monitor water quality management in intensive aquaculture which reduces preventive maintenance. [20][21] Intelligent predictive maintenance approach using supervised learning approach is implemented and performance of system evaluated.

[22] After reviewing the literature briefly, it’s found that there aren't many studies that use IIoT datasets, as can be shown from the survey. A supervised machine learning approach was also adopted by the majority of researchers to identify anomalous behaviour. However, data analysis might be challenging when there is a lack of specialised knowledge. Given the size of the data generated by IIoT, maintenance becomes challenging. This gave us the inspiration to start this research, where IIoT is the newest technology being used and satisfactory data analysis needs to be done. So, the main goal of unsupervised anomaly detection is to find previously unknown unusual things or events without having any prior knowledge of them. Anomaly detection often involves modelling the normal data distribution and defining a measurement in this space in order to categorise samples as anomalous or normal. This is because anomalies are uncommon and unknown to the user at training time. Unsupervised anomaly detection uses a dataset that has not been labelled. It looks for data

points that are different from the "normal" data points on the assumption that the bulk of the unlabelled data points are "normal."

3. Proposed Methodology

3.1 Data Acquisition

Five Layer architecture is used for proposed system such as things layer as sensor layer used to connect different sensor according to requirement in industrial scenario, Edge layer where system uses Node MCU ESP 32, fog layer where intelligence using data analytics is performed, communication layer & cloud services for acquiring data as shown in fig 1. Components detail for Architectural Implementation with its used is shown in Table I.

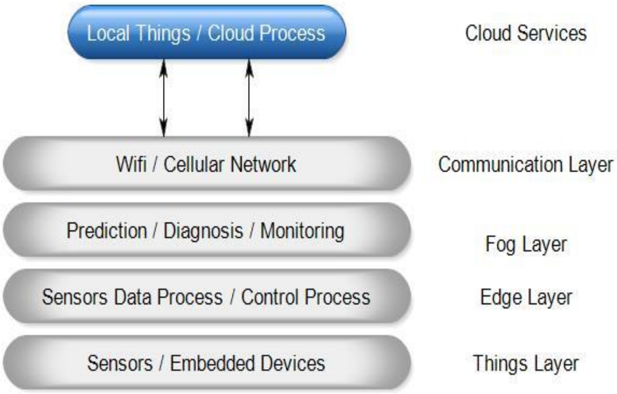

Figure 1. Layer Architecture proposed work

Table 1. Components detail for Architectural Implementation.

S. No	Component	Used in system
1	Two Node MCU ESP 32	Interfacing sensor as per indoor & outdoor scenario requirement for operations within industry
2	DHT22, DHT11	Indoor & Outdoor Temperature & Humidify respectively.
3	MQ2	Gas Leakage detection Indoor
4	LDR	Intensity of light is to captured in an environment during measurement of colour calibration of object in Process industry in indoor environment.
5	E18	Presence or Absence of manufacturing object can be detected with infrared proximity sensor in Indoor scenario.
6	DS18B20	Outdoor Boiling Temperature is monitor using digital temperature sensor
7	MQ135	Air Quality Outdoor

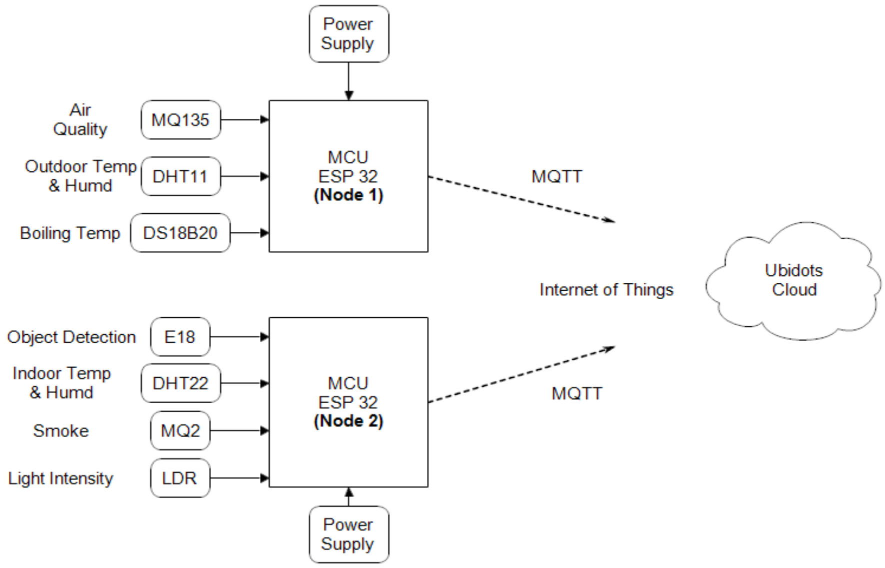

Figure2. Architectural diagram for Implementaion of system

The flow of work which is to be carry out is shown in fig 3 in which there is process of acquiring data from sensor & sending the data on cloud for monitoring purpose.

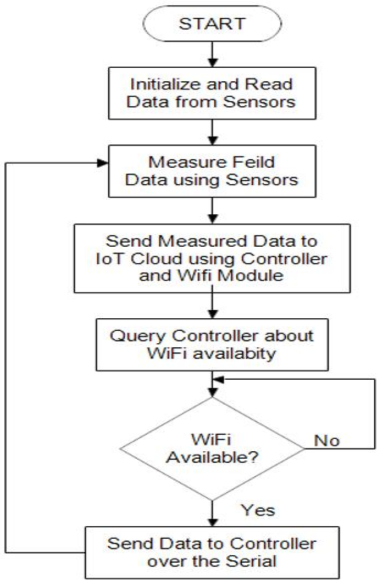

Figure 3. Flowchart of proposed work

3.2 Data Analytics

Once the system is installed data acquisition & data collection is done which is followed by data pre-processing then anomaly detection model using clustering approach is built at fog layer to determine the performance of system using different unsupervised machine learning approach. The flow of data analytics approach is shown in figure 4.

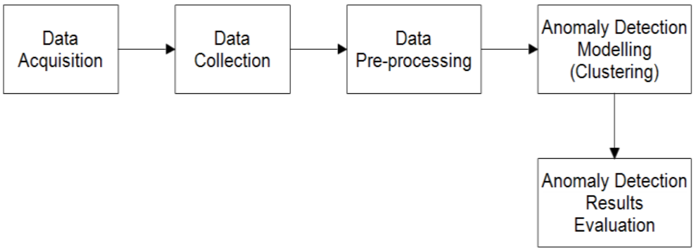

Figure 4. Data Analytics

4. Results and Discussion

The experimental plan for proposed system is implemented on a prototype that has been tested practically for various conditions. As per as programming of node controller is concerned it is written in embedded C language with Arduino IDE. The analytics and decision-making model and classification is performed on a system having laptop with a 2.30GHz Intel (R) Core (TM) CPU, 8GB RAM, and Windows 10 (64 bit) operating system. The MATLAB IDE is used to program the intelligent model, in which statistics, and machine learning toolbox from MATLAB is utilized as tools. When an anomaly is discovered in the data, two nodes exhibiting sensor readings for outdoor and indoor scenarios in industry are monitored for abnormal and normal situations and shown on the cloud as appropriately. The supervisor can manage the situation to maintain process control. In order to discover anomalous behaviour in sensed data, the system is now being evaluated with an unsupervised machine learning technique employing fuzzy c-means, k-means clustering, and DBSCAN & clustering algorithm.

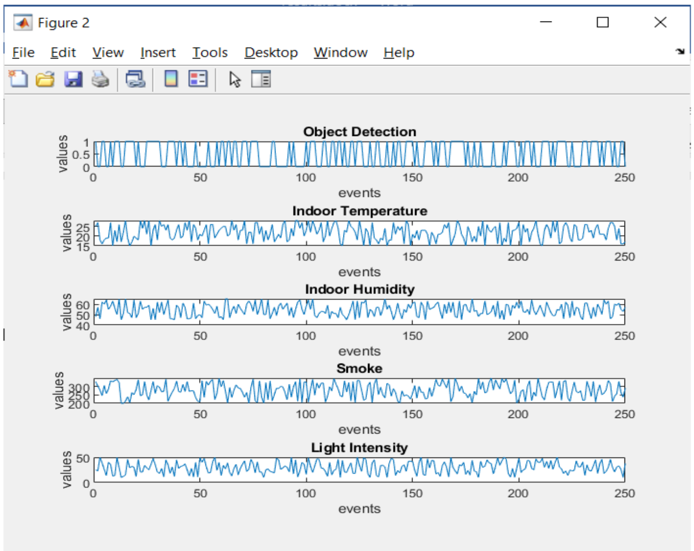

Figure 5. Test data of proposed model for outdoor environment

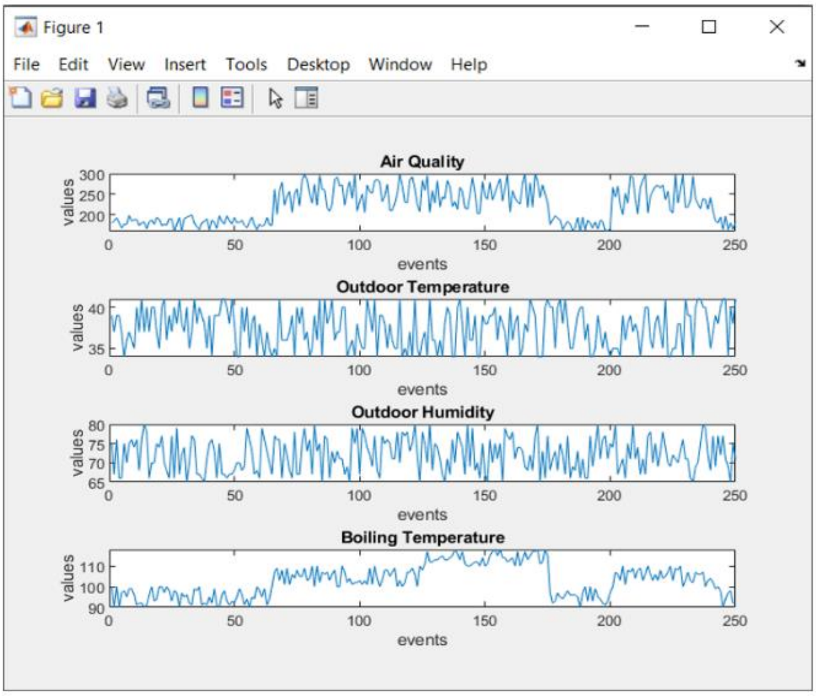

Figure 6. Test data of proposed model for indoor environment

On the basis of sensor data, techniques are discovered to be potential candidates for anomaly identification and condition monitoring of industry-related equipment's systems. Using the previously discussed cluster-based unsupervised approach for predictive maintenance, the suggested model for an outdoor and indoor environment, is tested using the data shown in Fig. 5 and 6 which is acquired from sensor for indoor and outdoor scenario for which we are detecting anomaly for prediction of normal & abnormal behaviour.

4.1 Algorithm

The algorithm used for prediction of faults using unsupervised approach are Fuzzy c-means clustering, k-means clustering & DBSCAN The clusters for outdoor parameter on Node1 for temperature, air Quality, and humidity and boiling temperature using Fuzzy c-means clustering approach is shown in fig 7 (a), (b) & fig (c), (d), where it represents cluster assignments and centroids for outdoor parameters as shown in respective figures where sensed data is interpreted for two clusters with its respective centroids. Similarly, clusters for Node 2 using Fuzzy c-means clustering approach for indoor Environment is plotted. The clusters for indoor parameter on Node2 using Fuzzy c- means clustering approach is shown in fig 8 (a), (b), (c), (d), (e) where fig (a) represents cluster assignments and centroids for indoor humidity, light intensity, object detection, smoke and temperature sensed data is interpreted for two clusters with its respective centroids shown in figure.

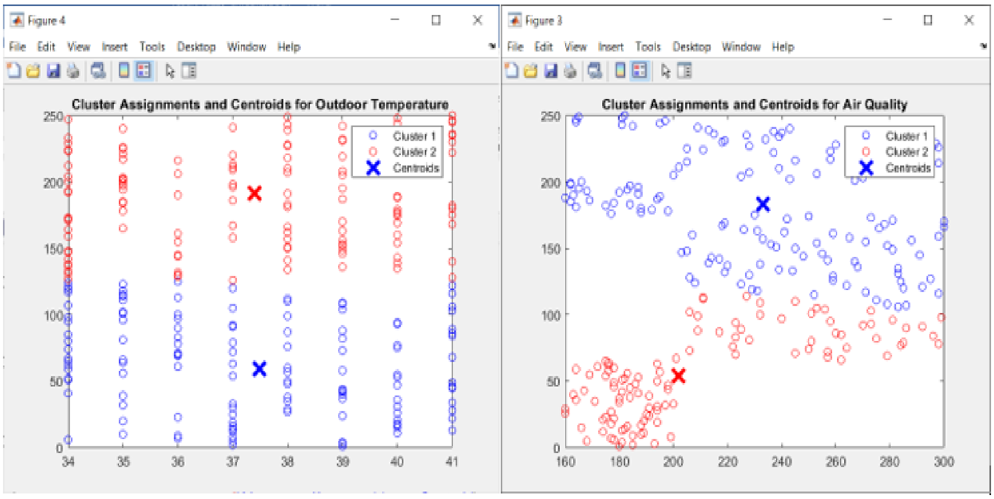

Figure 7(a), (b). Clusters for Node 1 Outdoor temperature & Air Quality

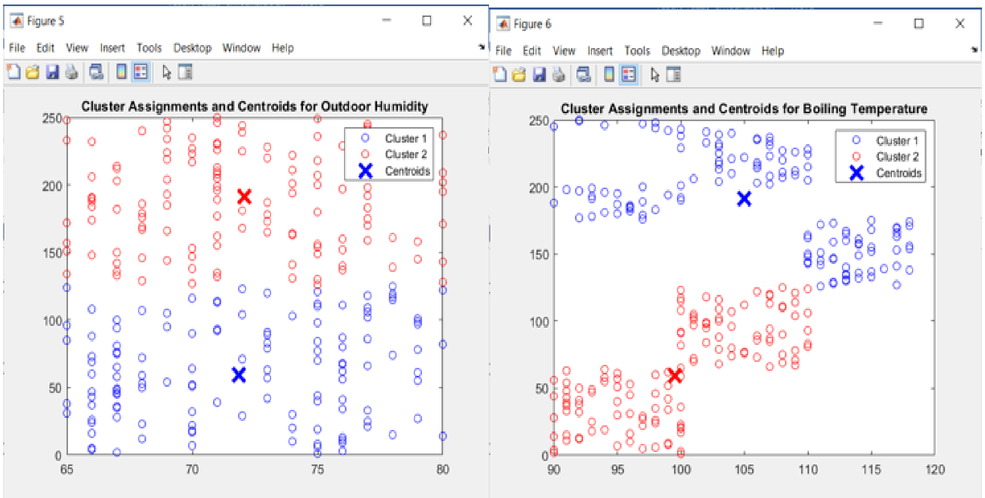

Figure 7 (c), (d). Clusters for Node 1 Outdoor Humidity & Boiling Temperature parameters

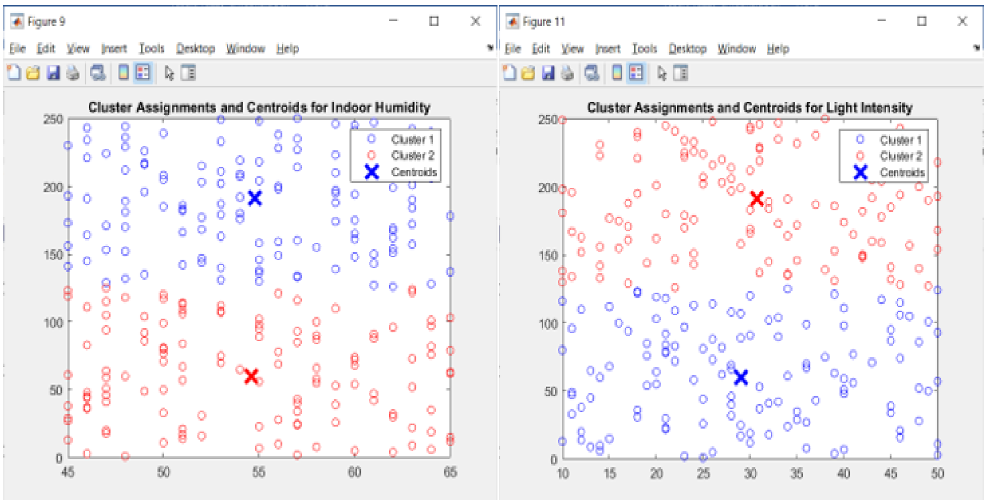

Figure 8(a), (b). Clusters for Node 2 Indoor humidity & Light intensity

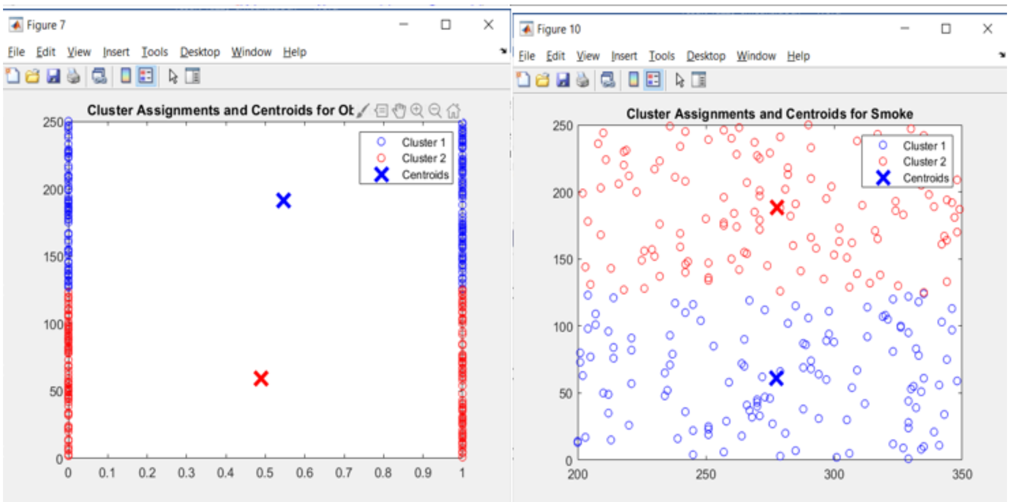

Figure 8(c), (d). Clusters for Node 2 indoor Object detection & Smoke

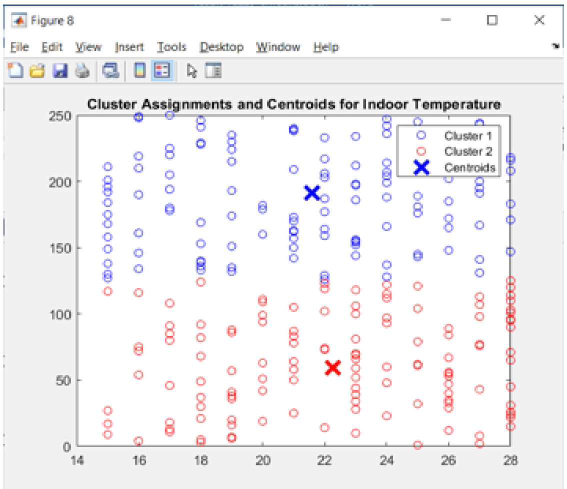

Figure 8(e). Clusters for Node 2 indoor temperature

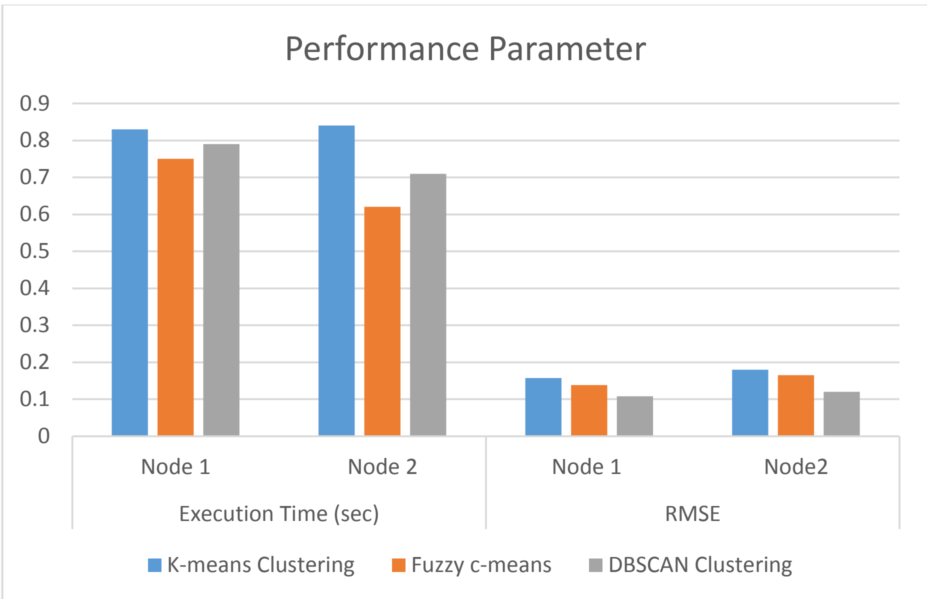

Figure 9. System performance

Table 2. Performance Parameters

Method	Execution Time (sec)		RMSE	
	Node 1	Node 2	Node 1	Node2
Fuzzy c-means	0.75	0.62	0.138	0.165
K-means Clustering	0.83	0.84	0.157	0.180
DBSCAN Clustering	0.79	0.71	0.108	0.120

The system is also analysed using another clustering approaches like k-means clustering and DBSCAN for indoor & Outdoor environment for different parameters as mentioned above & performance of both the approach is evaluated.

5. Conclusion

The proposed experimentation illustrated the design of the IIoT solution, described the prototype industrial plant during normal and abnormal operation, analysed with unsupervised machine learning approach by using clustering algorithms and presented the anomaly detection of sensor data analysis to create a smart operating condition based on industrial scenario. The methods applied in this proposed approach consist of, fuzzy c-means, k-means clustering and density-based clustering. Mostly, cluster-based methods are found to be significant approach for anomaly detection and situation monitoring of industrial equipment's systems rely on sensor data. The result shows that proposed scheme is accurate and efficient for Industrial scenario.

References

[1] Ran, Yongyi, Xin Zhou, Pengfeng Lin, Yonggang Wen, and Ruilong Deng. "A survey of predictive maintenance: Systems, purposes and approaches." arXiv preprint arXiv:1912.07383 (2019).

[2] S. R. Pokhrel, S. Verma, S. Garg, A. K. Sharma and J. Choi, "An Efficient Clustering Framework for Massive Sensor Networking in Industrial Internet of Things," in IEEE Transactions on Industrial Informatics, vol. 17, no. 7, pp. 4917-4924, July 2021, doi: 10.1109/TII.2020.3006276.

[3] Y. Zhao, L. T. Yang and J. Sun, "Privacy-Preserving Tensor-Based Multiple Clustering's on Cloud for Industrial IoT," in IEEE Transactions on Industrial Informatics, vol. 15, no. 4, pp. 2372-2381, April 2019, doi: 10.1109/TII.2018.2871174.

[4] Sahil Sholla, Sukhkirandeep Kaur, Gh Rasool Begh, et_al "Clustering Internet of Things: A Review" journal of science and technology: issue on information and communications technology, vol. 3, no. 2, december 201721

[5] Sumegh Tharewal, Mohammed Waseem Ashfaque et_al "Intrusion Detection System for Industrial Internet of Things Based on Deep Reinforcement Learning" Wireless Communications and Mobile Computing Volume.2022, Article.ID.9023719,8 pages https://doi.org/10.1155/2022/9023719

[6] K. A. Abuhasel and M. A. Khan, "A Secure Industrial Internet of Things (IIoT) Framework for Resource Management in Smart Manufacturing," in IEEE Access, vol. 8, pp. 117354-117364, 2020, doi: 10.1109/ACCESS.2020.3004711

[7] D. Puschmann, P. Barnaghi and R. Tafazolli, "Adaptive Clustering for Dynamic IoT Data Streams," in IEEE Internet of Things Journal, vol. 4, no. 1, pp. 64-74, Feb. 2017, doi: 10.1109/JIOT.2016.2618909.

[8] Ungurean, Ioan, Nicoleta-Cristina Gaitan, and Vasile Gheorghita Gaitan. "An IoT architecture for things from industrial environment." In 2014 10th International Conference on Communications (COMM), pp. 1-4. IEEE, 2014.

[9] N. Amruthnath and T. Gupta, "Fault class prediction in unsupervised learning using model-based clustering approach," 2018 International Conference on Information and Computer Technologies (ICICT), 2018, pp. 5-12, doi: 10.1109/INFOCT.2018.8356831.

[10] C.S. Wickremasinghe, K. Amerasinghe, D. L. Marino, C. Rieger and M. Manic, "Explainable Unsupervised Machine Learning for Cyber-Physical Systems," in IEEE Access, vol. 9, pp. 131824-131843, 2021, doi: 10.1109/ACCESS.2021.3112397.

[11] N. Kolokas, T. Vafeiadis, D. Ioannidis and D. Tzovaras, "Anomaly Detection in Aluminium Production with Unsupervised Machine Learning Classifiers," 2019 IEEE International Symposium on INnovations in Intelligent SysTems and Applications (INISTA), 2019, pp. 1-6, doi: 10.1109/INISTA.2019.8778419.

[12] Oliveira, David FN, Lucio F. Vismari, Jorge R. de Almeida, Paulo S. Cugnasca, João B. Camargo, Eduardo Marreto, Debora R. Doimo, Leandro PF de Almeida, Rafael Gripp, and Marcelo M. Neves. "Evaluating unsupervised anomaly detection models to detect faults in heavy haul railway operations." In 2019 18th IEEE International Conference On Machine Learning And Applications (ICMLA), pp. 1016-1022. IEEE, 2019.

[13] J. Penfield and M. Holland, "Using Unsupervised Machine Learning for Online Monitoring of Turbine-Generator Bearings in Hydro-Electrical Generating Stations,"

2021 IEEE PES/IAS Power Africa, 2021, pp. 1-5, doi: 10.1109/PowerAfrica52236.2021.9543428.

[14] Voß, Carlo, Benedikt Eiteneuer, and Oliver Niggemann. "Incorporating Uncertainty into Unsupervised Machine Learning for Cyber-Physical Systems." In 2020 IEEE Conference on Industrial Cyberphysical Systems (ICPS), vol. 1, pp. 475-480. IEEE, 2020.

[15] M. Berno et al., "A Machine Learning-based Approach for Advanced Monitoring of Automated Equipment for the Entertainment Industry," 2021 IEEE International Workshop on Metrology for Industry 4.0 & IoT (MetroInd4.0&IoT),2021, pp.386-391, doi:10.1109/MetroInd4.0IoT51437.2021.9488481.

[16] N. Soltanipour, S. Rahrovani, J. Martinsson and R. Westlund, "Chassis Hardware Fault Diagnostics with Hidden Markov Model Based Clustering," 2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC), 2020, pp. 1-6, doi: 10.1109/ITSC45102.2020.9294468.

[17] C.Charoenchitt and P. Tangamchit, "Anomaly Detection of a Reciprocating Compressor using Autoencoders," 2021 Second International Symposium on Instrumentation, Control, Artificial Intelligence, and Robotics (ICA-SYMP), 2021, pp. 1-4, doi: 10.1109/ICA-SYMP50206.2021.9358453.

[18] Y. Dong, C. Zhou, Z. Wu and M. Cheng, "Dual Mix-up Adversarial Domain Adaptation for Machine Remaining Useful Life Prediction," 2022 IEEE 5th International Conference on Electronics Technology (ICET), 2022, pp. 573-578, doi: 10.1109/ICET55676.2022.9824464.

[19] Christian Velasco-Gallego, Iraklis Lazakis “RADIS: A real-time anomaly detection intelligent system for fault diagnosis of marine machinery” Expert Systems with Applications 204(2022) 117634.

[20] M. Kostoláni, J. Murín and Š. Kozák, "An effective industrial control approach," 2019 Federated Conference on Computer Science and Information Systems (FedCSIS), 2019, pp. 911-914, doi: 10.15439/2019F187.

[21] S. Liu, L. Xu, Q. Li, X. Zhao and D. Li, "Fault Diagnosis of Water Quality Monitoring Devices Based on Multiclass Support Vector Machines and Rule-Based Decision Trees," in IEEE Access, vol. 6, pp. 22184-22195, 2018, doi: 10.1109/ACCESS.2018.2800530.

[22] U. W. Hore and D. G. Wakde, "Context Aware IoT Enabled Framework for Monitoring Parameters from Industrial Perspective," 2022 10th International Conference on

Emerging Trends in Engineering and Technology - Signal and Information Processing (ICETET-SIP-22), 2022, pp. 1-6, doi: 10.1109/ICETET-SIP-2254415.2022.9791787.

Author's biography

Umesh W. Hore is currently working as Assistant Professor in Electronics & Telecommunication Department at P. R. Pote college of Engineering & Management, Amravati. He is having more than 18 years of experience in teaching & published many papers in international journal & conferences. His area of interest is embedded system & IoT.

D. G. Wakde is working in Education sector more than 35 years. During his tenure he had handled several responsibilities as a Director & Principal in various educational institution. He has guided number of Ph.D. scholar & presently working as PhD supervisor in Sant Gadge baba Amravati University Amravati.