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Original Article

IoT-Driven Real-Time Data Collection and Analysis for Lean Manufacturing

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Abstract *- Internet of Things (IoT) offers a great opportunity for manufacturers to optimize their production process. With the use of IoT, manufacturers can now collect and analyze real-time data from various points across the manufacturing process, empowering them to make proactive and informed decisions, leading to improved process efficiency and productivity. This data can be used to identify and diagnose outliers, understand their root causes, and develop strategies to rectify them. This real-time data also allows manufacturers to adjust the production process in real time in order to reuse resources and minimize waste. The collected data can also be used to monitor product quality, predict machinery service requirements, and automate production line operations, increasing operation efficiency and safety. The use of IoT in lean manufacturing holds tremendous potential for optimizing production and achieving greater cost savings. Moreover, real-time data collection and analysis allow manufacturers to become more agile and reactive to changing customer needs and market conditions.*

Keywords *- IoT, Manufacture, Production, Decision, Efficiency, Productivity.*

1. Introduction

The utilization of IoT-driven real-time data collection and analysis plays a critical role in lean manufacturing practices today. It enables organizations to monitor and optimize critical resources to improve efficiency, reduce costs, and create a safer, smarter, and greener manufacturing environment. One of the primary benefits of IoT-driven real-time data collection and analysis is the ability to have real-time access to data from multiple sources, including machines, plants, and other resources. This data can inform decisions about how to utilize resources in a lean manner best. For instance, the data can help identify process inefficiencies and plant downtime that can be addressed to optimize production. This not only increases efficiency but also can lead to cost savings [1]. Another advantage is the ability to track and analyze the performance and health of machines and other resources. This can help manufacturers identify and address potential issues before they lead to costly downtime or product and safety concerns. This data can also provide information about areas where improvements can be implemented. For example, if a sensor detects something abnormal in a machine, an operator can take action to prevent any damaging issues or costly downtime. Finally, utilizing IoT-driven data can enable manufacturers to create a safer, smarter, and greener environment through energy optimization. By collecting real-time data on energy usage, companies can identify areas where energy consumption can be reduced. This can help improve air quality, conserve resources, and reduce environmental impact. It also reduces operational costs by reducing energy consumption and decreasing emissions [2]. The importance of IoT-driven real-time data collection and analysis for lean manufacturing cannot be understated. It allows organizations to monitor better and optimize their resources, identify inefficiencies and act quickly to address potential issues and reduce energy usage and environmental impact. By leveraging IoT-driven data, organizations can position themselves to become more efficient, sustainable, and competitive in the global marketplace.

The Internet of Things (IoT) is revolutionizing manufacturing processes. An IoT-driven real-time data collection and analysis system is enabling lean manufacturing operations. This system can provide deeper insights into every aspect of a production cycle, from the beginning of the process to the end. This data can then be used for timely decisions on process optimization and product development. The system begins by continuously collecting and collating data points from all areas of the production cycle. This data is then used to monitor and assess the performance of the process continuously. For example, IoT sensors can track the energy, speed, and accuracy of machines, as well as the workflow from each stage. This system also collects information from production records, such as defects, scrap rate, materials utilized, and lead time [3]. This data is often used to detect process bottlenecks and issues. By analyzing the data collected, problems can be identified and addressed quickly. This prevents wastage and cost overruns and minimizes the production cycle time. In addition, the data collected can be

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used to improve the production process further. For example, by studying the defects, steps can be taken to reduce the number of defects in the future.

Additionally, by studying the different materials used in production, the most cost-effective materials can be identified. IoT-driven real-time data collection and analysis for lean manufacturing helps to increase efficiency and reduce waste. The insights that are gained from this data provide opportunities for process improvement and cost savings. This leads to a higher quality product, delivered faster, which translates to improved customer satisfaction. With a better understanding of the production process, companies also have opportunities to develop and introduce new products quickly and effectively. The construction diagram is shown in the following Figure 1.

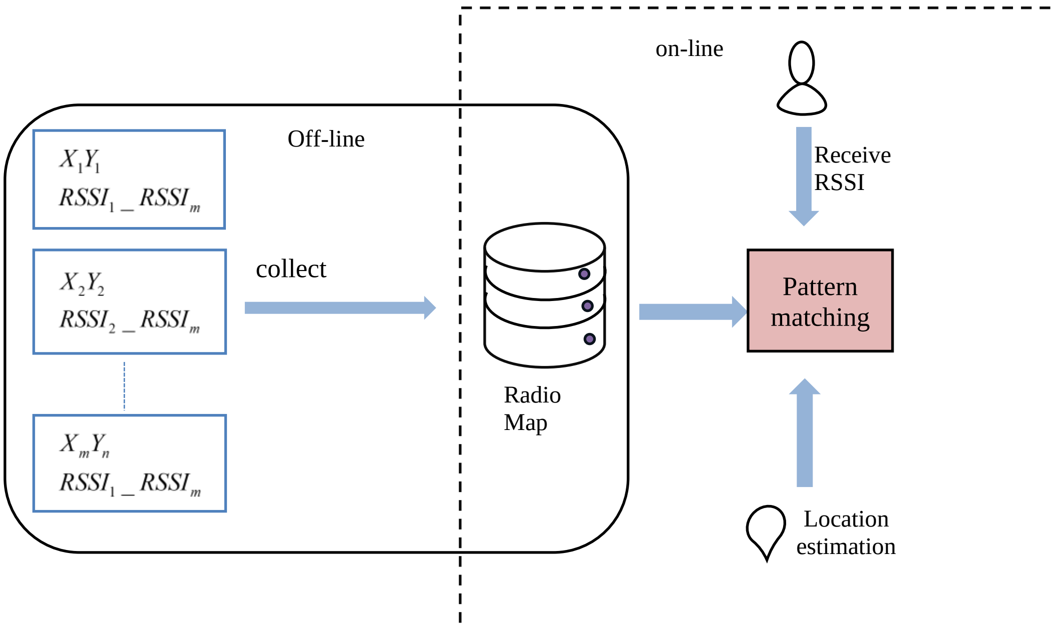

Fig. 1 Construction diagram

The data collected and analyzed provides the foundation for predicting future production and development trends. This helps to optimize resources, streamline processes, and reduce risk. Ultimately, this enables manufacturers to become more competitive and stay ahead of industry trends. IoT-driven real-time data collection and analysis for lean manufacturing is revolutionizing processes and increasing operational efficiency in manufacturing [4]. By providing deeper insight into production and reducing waste, it is boosting companies' competitiveness and helping them to stay at the cutting edge of the market. This is a technology that companies should be taking advantage of if they are serious about their success in manufacturing. The main contribution of the research has the following,

- Improved visibility of production line conditions and processes: IoT-driven real-time data collection and analysis allows visibility into production line conditions and processes in order to detect problems and inefficiencies that can be quickly addressed.
- Reduced inventory: Accurate real-time data on inventory level, component availability, and manufacturing progress helps streamline production processes and reduce costs associated with mismanagement or stocking of unnecessary parts.
- Increased efficiencies: By providing real-time information, IoT-driven real-time data collection and analysis can be used to reduce costs and improve process quality and throughput.
- Accelerated time to market: Real-time collection and analysis of data helps identify manufacturing process problems that can be addressed quickly to meet customer demands.
- Improved scalability: By providing a better view of operations, IoT-driven real-time data collection and analysis can provide insights that help manufacturers scale production more effectively.
- Enhanced customer service: By providing more detailed information about product and delivery status to customers, it is easier to keep them informed and satisfied [5-7].

2. Literature Review

In the past few years, the IoT (Internet of Things) has become an increasingly popular technology that is enabling manufacturers to reap the benefits of real-time data collection and analysis in order to take advantage of its lean manufacturing processes. This has allowed them to improve the efficiency and accuracy of their production operations.

Being able to monitor and control production processes remotely from anywhere in the world and to collect real-time data from the machines and their environment, such as temperature, pressure, and vibration is essential in order for companies to gain full visibility of their manufacturing environment. The IoT offers the ability to streamline processes and reduce downtime while also allowing for the integration of centralized data sources, which helps achieve better response times, improved quality, and greater accuracy [8]. Additionally, the IoT can help to reduce waste, increase productivity, and optimize cost in relation to production. Additionally, the ability to collect real-time data gives manufacturers an insight into their production processes, allowing them to make informed decisions and quickly and accurately address problems. However, despite the numerous benefits of incorporating the IoT into production processes, there are still some issues associated with real-time data collection and analysis that need to be considered. One of them is data privacy and security. The IoT helps manufacturers collect vast amounts of data, which means it also leaves them exposed to the risk of cyber-attacks and data theft. For this reason, manufacturers need to stay up-to-date on the latest security measures and make sure that stringent data protection policies are being followed. Additionally, an efficient data management system is necessary in order to ensure that only the most relevant and accurate information is being collected [9]. Furthermore, the IoT platforms used in lean manufacturing processes can be complex and difficult to manage. A lack of understanding of the technology can lead to inefficiencies and even cause disruption in the production process. It is, therefore, important to have an adequate support system in place to help navigate any technical challenges that arise. The IoT is a powerful tool that has revolutionized the production environment through improved real-time data collection and analysis capabilities. Despite the potential issues associated with such technology, the benefits of leveraging the IoT for lean manufacturing are such that most companies feel it is a worthwhile investment. The emergence of the Internet of Things (IoT) has enabled real-time data collection and analysis for lean manufacturing, with a vast array of devices connected to a single network [10]. By connecting machines, products, personnel, and the environment, digital sensing and monitoring of production processes can greatly reduce physical waste, saving time and money as production becomes more efficient. However, the collection of data through IoT presents its own unique problems. For starters, the sheer amount of data collected is daunting. Even with powerful computing capabilities, it can be difficult to process and make sense of large data sets in real time. Furthermore, most IoT-driven systems rely on complex communication protocols for data transmission, which can be complicated to set up and manage. Additionally, much of this data is sensitive in nature and is subject to rigorous privacy regulations. This brings about another issue: companies must take steps to ensure that data is collected, transmitted, and stored securely in order to remain compliant. Another problem of IoT-driven data collection for lean manufacturing is the risk of error. The analysis is only as good as the data collected, and if the data is inaccurate, then decisions based on that data will be flawed [11]. Inaccuracies are often caused by equipment malfunctions or human error. System designers must account for these errors in order to ensure accuracy in the data collected. Additionally, as data becomes more complex, the processing complexity should be taken into account, as algorithms that process high-complexity data require greater computational power and may be unable to keep up with real-time production processes. The companies that conduct real-time data collection and analysis for lean manufacturing must also take into account the cost of setting up and maintaining the system. Polling data from multiple machines can become expensive, and the cost must be taken into account when budgeting for the system. Furthermore, there is also the cost associated with properly training personnel in the proper use of the system, including adapting to new tools or processes as production alters. While the collection of real-time data through IoT can lead to increased efficiency and cost savings for lean manufacturing, there are several issues that need to be addressed [12]. Companies must be diligent in ensuring that data is collected, transmitted, and stored securely. Additionally, system designers must be mindful of potential errors and complexities in order to create accurate and reliable data. Moreover, finally, companies must factor in the cost of setting up and maintaining the system in order to realize the full potential of the data produced.

The novelty of the research is that IoT-driven real-time data collection and analysis for lean manufacturing brings a whole new level of granular feedback to the production process, enabling the system to be more proactive than ever before. By leveraging the power of the Internet of Things (IoT), data can be collected, stored and analyzed in real-time, allowing producers to quickly detect abnormalities in the performance of their machinery and take quick action to streamline processes, improve operational efficiency and reduce costs [13-15]. Real-time data collection and analysis also provide the opportunity to monitor production line output, making it easier to identify and address areas of potential improvement. With the help of analytics, companies can also come up with strategies that optimize their manufacturing processes according to numerous factors.

3. Proposed Model

IoT-driven real-time data collection and analysis for lean manufacturing is an automated process that allows manufacturers to collect and analyze data from multiple sources in real time to support Lean Manufacturing. IoT-driven data collection gives manufacturers insight into the performance of machinery, processes, and worker activities in order to identify and eliminate waste and inefficiencies throughout the production process. Through the use of connected sensors, cameras, and other connected devices, manufacturers can monitor equipment performance, detect malfunctions, identify potential operational issues, and make adjustments in real time to improve efficiency and reduce waste.

$$\partial v' = \lim_{v \to 0} \left(\frac{\partial u^{v+u} - \partial v^{u}}{\partial u} \right) \quad (1)$$

IoT-driven data analysis can provide manufacturers with valuable insights into how to manage their operations better, reduce costs, increase production, and improve product quality. By understanding what works best and what needs to be improved, manufacturers can become more agile and responsive to customer demands and stay competitive in the market.

3.1. Construction

Internet of Things (IoT) is a revolutionary technology that has introduced a new wave of digital transformation and automation to various industries, with the manufacturing industry being no exception. IoT-driven real-time data collection and analysis offers a number of unique benefits to the field of lean manufacturing, which is focused on eliminating waste and delivering greater efficiency.

$$\partial v'' = \lim_{v \to 0} \left(\frac{\partial (v^{u} * v^{u}) - \partial v^{u}}{\partial u} \right) \quad (2)$$

This technology allows manufacturers to monitor better, analyze, and optimize their processes to improve their long-term performance. The first major benefit of IoT-driven real-time data collection and analysis is the ability to make informed decisions. Manufacturers can leverage the real-time data from IoT sensors to analyze and identify trends, detect issues, and adjust processes in a timely manner. The functional block diagram is shown in the following Figure 2.

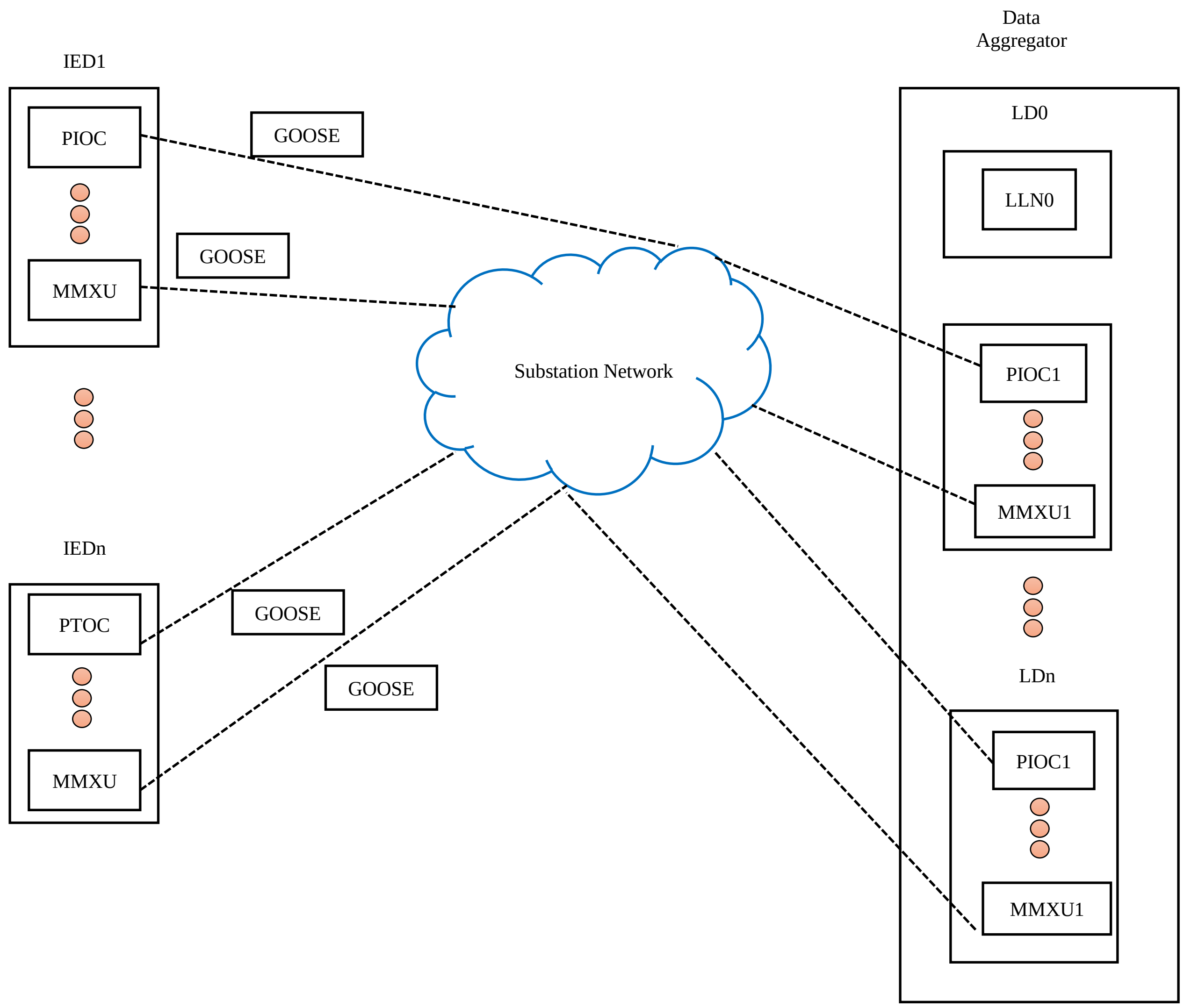

Fig. 2 Functional block diagram

This enables manufacturers to quickly identify and address issues and optimize processes to improve quality and productivity. Additionally, IoT-driven data collection can provide manufacturers with detailed insights into their operations, allowing them to spot potential issues before they become major problems. The second major benefit of IoT-driven real-time data collection and analysis is improved cost optimization. IoT-driven data collection technologies can improve harmony across the entire supply chain, helping to maximize the use of resources and minimize wastage.

$$p" = q^r * \lim_{r \to 0}\left(\frac{(q^p - 1)}{p}\right) \tag{3}$$

Additionally, IoT-driven data collection technologies can be used to optimize and automate production processes, further reducing costs. This helps to improve the efficiency of operations and ultimately boosts performance. The third major benefit of real-time data collection and analysis is improved accuracy. By collecting accurate, up-to-date data, manufacturers can make more informed decisions. For example, precise data about production orders, materials, and processes can allow manufacturers to make the most efficient use of resources to maximize the output and minimize errors.

$$q_p^2 = \left(\frac{R * R_p}{S_p}\right) * \frac{2}{R} \tag{4}$$

IoT-driven real-time data collection and analysis offers manufacturers significant benefits in terms of informed decisions, cost optimization, and accuracy. This technology allows manufacturers to leverage real-time data to monitor better, analyze, and optimize processes to improve long-term performance. As IoT-driven data collection and analysis continues to evolve and expand, it will become even more useful in the lean manufacturing process.

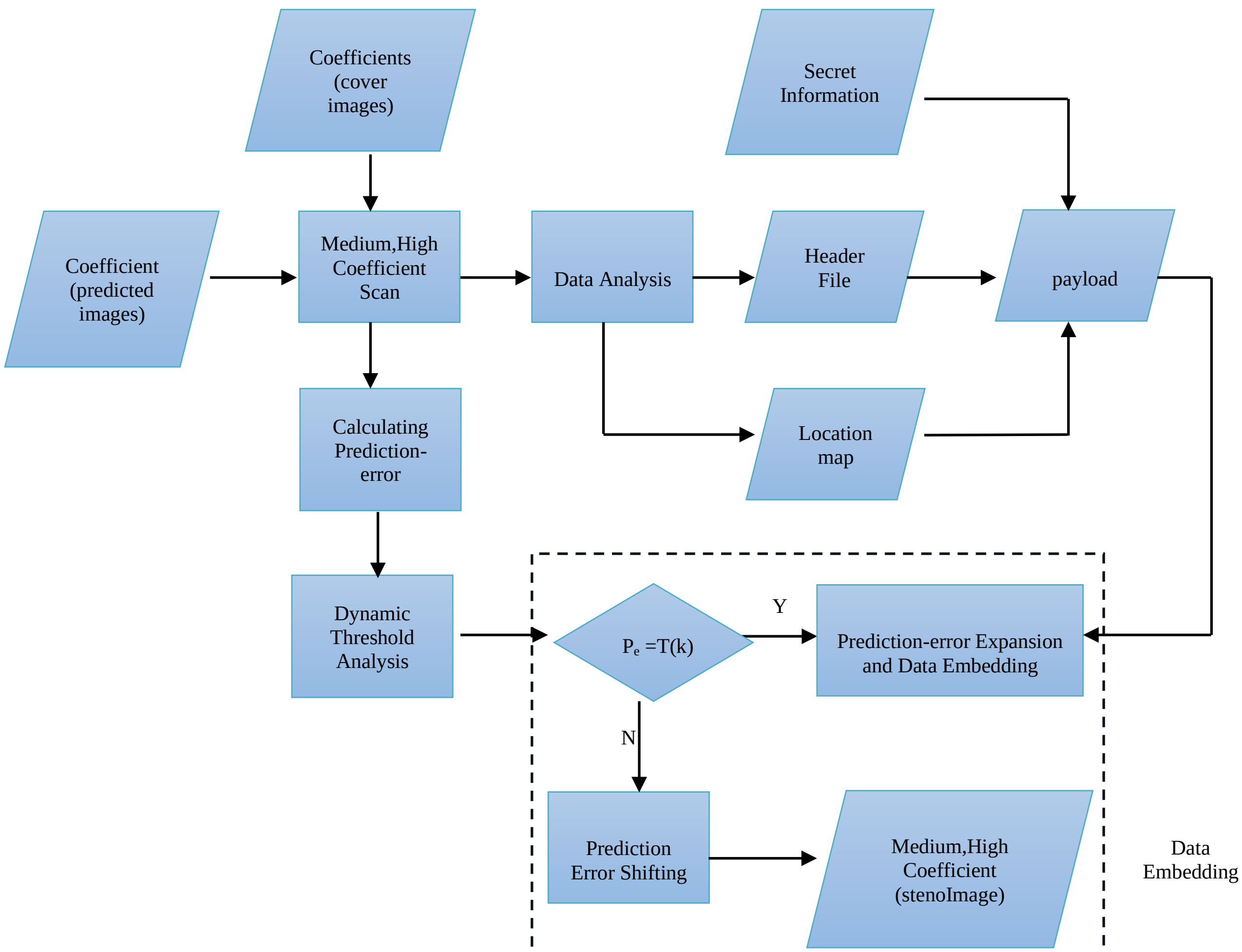

Fig. 3 Operational flow diagram

3.2. Operating Principle

The operating principle of IoT-driven real-time data collection and analysis for lean manufacturing is that, by connecting various pieces of equipment to a central system through the Internet of Things (IoT), a manufacturer can receive real-time data about their operations. This data can be analyzed to identify areas of inefficiency, reduce waste, and streamline operations. With this data, manufacturers can more quickly identify and respond to issues in their processes.

$$\partial v = \lim_{u \to 0} \left(\frac{\partial v^u * \partial (v^u - 1)}{\partial u} \right) \quad (5)$$

This enables the manufacturer to adjust their processes if needed quickly and to seek opportunities for improvement. Additionally, the data can be used to hold employees accountable for their work, ensuring that their tasks are being completed to the desired specifications.

3.3. Functional Working

IoT (Internet of Things) is a growing trend that is transforming many industries, including Lean Manufacturing. By connecting devices in new ways, manufacturers are able to collect and analyze real-time data from remotely located sensors and machines to gain insights into the efficiency and performance of production processes.

$$\partial u" = \partial v^u * \lim_{u \to 0} \left(\frac{\partial (v^u - 1)}{\partial v} \right) \quad (6)$$

This data allows for faster decision-making and the ability to identify improvements to reduce waste. The key component of using IoT-driven real-time data collection and analysis for Lean Manufacturing is the ability to identify and eliminate waste. By using automated sensors and machinery, information is gathered and sent to a centralized database where it can be measured in real time. The operational flow diagram is shown in the following Figure 3.

This data is then used to identify processes or products that are consuming too much time or have a higher defect rate. With this information, the manufacturer can identify areas of improvement and reduce waste. This data can also be used to plan ahead to avoid any sudden decreases in productivity and increase efficiency.

$$dU = dV^u * \ln(V) \quad (7)$$

By combining data from multiple sources, manufacturers are able to gain a better understanding of the entire production process. This enables them to identify areas where process times and costs can be reduced. Furthermore, data analysis allows manufacturers to reduce lost time due to defects, breakdowns, or just inefficient processes.

$$\left(\frac{dU * dU_u}{dV_u} \right) = \frac{1}{2} dU * dV_u^2 \quad (8)$$

Moreover, real-time dynamic dashboards provide insights into the performance of production and the performance of individual machines, thus allowing early warnings for any weak points in the production line. Using IoT-driven real-time data collection and analysis for Lean Manufacturing is a game-changer.

$$dv_u^2 = \left(\frac{dU * dU_u}{dV_u} \right) * \frac{2}{du} \quad (9)$$

$$dV_u^2 = \left(\frac{2 * dU_v}{dV_u} \right) \quad (10)$$

With IoT-enabled sensors, manufacturers can gain insights into their production process and identify areas of improvement. This allows for faster decision-making and the ability to reduce waste and ensure that products remain of the highest quality. The result is a more optimized and efficient Lean Manufacturing line that produces higher-quality products quickly and at a lower cost.

4. Results and Discussion

The comparative analysis of IoT-Driven Real-Time Data Collection and Analysis for Lean Manufacturing allows companies to analyze the performance of their manufacturing processes in real time and make necessary updates. This type of data collection provides greater accuracy, faster response times, quicker decision-making, and improved reliability. It enables companies to reduce costs, increase efficiency, and optimize quality. It also provides a means to identify opportunities for process improvements. The real-time data analysis of IoT-driven data collection can significantly reduce the time spent on manual data collection and analysis. It eliminates redundant and often time-consuming tasks associated with manual data collection and analysis. Moreover, it also eliminates occurrences of human error associated with manual data collection. Real-time data collection and analysis also aid in more accurate analysis and decision-making. Real-time data provides an up-to-date view of the state of production, allowing companies to make more informed decisions. This can lead to improved predictability in the production process, increased efficiency, and streamlined operations. Finally, real-time data collection and analysis can also help to improve the quality of the process. By providing timely and accurate data, companies can better identify areas of improvement and ensure that those processes are being carried out optimally. This can ultimately improve the overall quality of the product. The comparative analysis of IoT-driven real-time data collection and analysis for Lean Manufacturing offers several advantages over the traditional manual methods of data collection. It can provide greater accuracy, faster response times, better decision-making, reduced costs, increased efficiency, and improved quality. Ultimately, this type of data collection and analysis can help companies optimize their Lean Manufacturing processes and achieve greater success. The performance of the proposed method has been compared with CVIC- Computer Vision and Image-based Classification, MLRA- Machine Learning for Real-Time Analysis and LMIoT- Lean Manufacturing IoT.

4.1. Performance Analysis of Latency

The performance analysis of IoT-Driven real-time data collection and analysis for lean manufacturing provides efficient utilization of data generated through connected manufacturing devices. The analysis helps to explore problems and allows teams to reduce costs, identify areas of inefficiency, and optimize processes. The performance analysis offers insights into the operations and performance of the systems driving the production process. Table 1 gives the comparison of various algorithms for Latency.

Table 1. Comparison of latency (in %)

No. of rounds	CVIC	MLRA	LMIoT	Proposed
100	75.33	87.26	81.71	93.48
200	75.00	85.76	81.12	91.61
300	73.66	84.65	80.14	90.78
400	72.52	84.27	78.93	89.87
500	71.47	83.26	77.79	88.95

The performance analysis is shown in the following Figure 4.

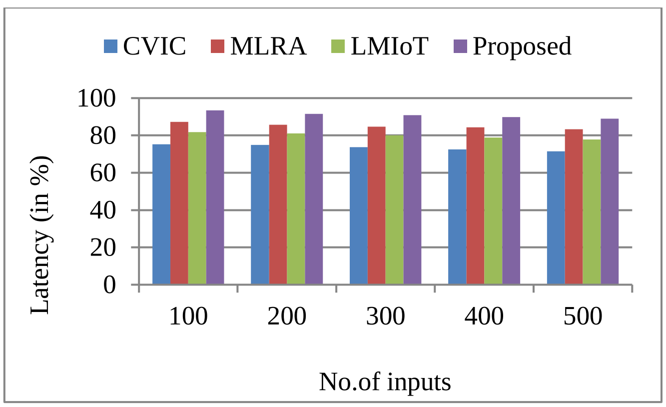

Fig. 4 Latency

It provides alerts about any anomalies or discrepancies in the data and can be used to predict future performance. This enables decision-makers to act swiftly and make proactive changes in the processes to ensure continuous improvement and efficiency. Furthermore, data collected from IoT-driven manufacturing solutions can provide insights into the root cause of any downtime as well as identify areas where more resources are needed. The performance analysis can also be used to identify trends or patterns in the data collected which can be used for predictive maintenance. This can lead to improved asset utilization and reduce costs associated with equipment downtime. Finally, the data collected and analyzed through an IoT-driven solution allows for quick identification and resolution of production issues, helping to maximize the efficiency of the overall production process.

4.2. Performance Analysis of Reliability of Data

The Internet of Things (IoT) is changing the way that lean manufacturing is conducted. By utilizing IoT-driven real-time data collection and analysis, manufacturers can rapidly and accurately monitor their production processes. This real-time analysis of the production system allows for mitigated risks, predictive maintenance, deep insights, and, most importantly, optimization of the overall production system. The key to successful performance optimization of IoT-driven real-time data collection and analysis for lean manufacturing is to select the right technological platform. With the right platform, manufacturers can quickly achieve real-time insights and understand their production progress. Table 1 gives the comparison of various algorithms for Reliability.

Table 2. Comparison of reliability (in %)

No.of rounds	CVIC	MLRA	LMIoT	Proposed
100	78.33	83.26	83.71	88.48
200	78.00	81.76	83.12	86.61
300	76.66	80.65	82.14	85.78
400	75.52	80.27	80.93	84.87
500	74.47	79.26	79.79	83.95

The performance optimization is shown in the following Figure 5.

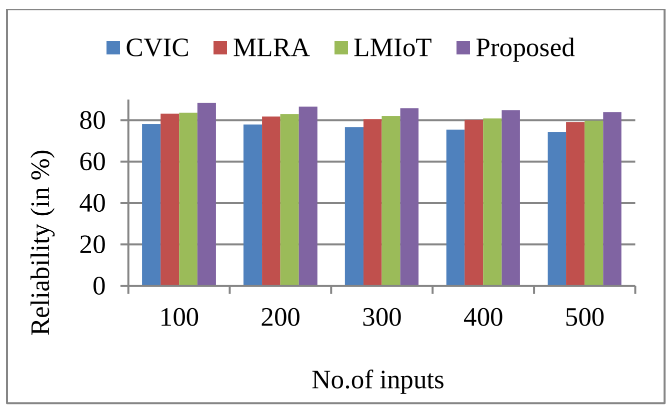

Fig. 5 Reliability

This helps them determine whether their operations are meeting their operational goals and requirements. Furthermore, it enables them to identify and take immediate corrective action the moment a discrepancy is detected. To gain maximum benefit from IoT-driven real-time data collection and analysis for lean manufacturing, the platform should also be designed in a way that it supports cloud-based storage, predictive analytics, machine learning, natural language processing, and automated reasoning. Through these technologies, the platform can automatically detect patterns, identify gaps, suggest improvements, detect and diagnose problems, and provide actionable analytics. The manufacturers should also implement fine-grain monitoring of production equipment and processes. By collecting data from the machines and processes over long periods of time, manufacturers can compare results over different periods and detect anomalies or trends. With real-time insights, manufacturers can act quickly to address issues and improve efficiency and productivity. The manufacturers should also ensure that their data assets are secure and regularly monitored for compliance with applicable data regulations. This is especially important given the ever-increasing threat landscape, which is seeing a rise in malicious data breaches and cyber-attacks. By choosing the right platform and implementing the correct processes and security measures, manufacturers can achieve maximum benefit from IoT-driven real-time data collection and analysis for lean manufacturing. This, in turn, will help manufacturers optimize their operations and eventually improve their overall performance.

4.3. Performance Analysis of Energy Consumption

The performance of lean manufacturing can be greatly enhanced through the integration of the Internet of Things (IoT) with real-time data collection and analysis. With the introduction of IoT-driven technologies, manufacturers are now able to effectively collect, store, and analyze data from machines and both physical and digital processes. The predictive data generated from this analysis offers insights into equipment performance and production efficiency. Table 1 gives a comparison of various algorithms for Energy Consumption.

The performance enhancement is shown in the following Figure 6.

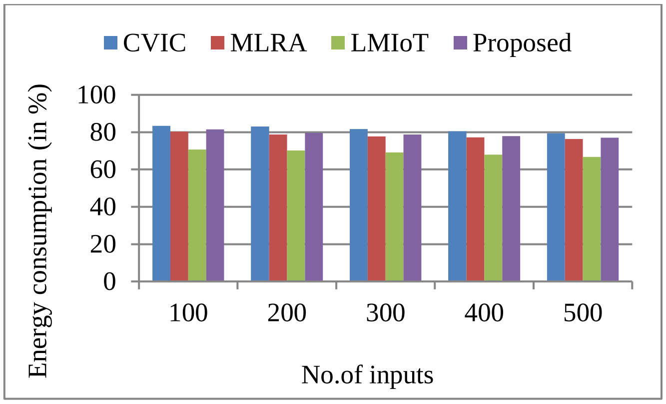

Fig. 6 Energy consumption

IoT-driven real-time data collection can allow manufacturers to monitor usage levels, identify inefficiencies, and optimize production processes. Manufacturers can also use IoT-driven analytics to analyze trends and develop models that enable predictive maintenance and operational changes that can improve efficiency. Additionally, real-time data can allow for timely responses and automated decisions, helping to minimize downtime and increase productivity. The introduction of IoT-driven data collection and analysis can also help to reduce waste and automate production operations, resulting in cost savings. By leveraging real-time data and analytics, manufacturers can optimize inventory levels, reduce overproduction, and lower error rates. These savings can then be invested in more efficient processes and better-quality components, allowing for a better bottom line. Overall, IoT-driven real-time data collection and analysis offers numerous advantages to lean manufacturing. With the introduction of IoT-driven technologies, manufacturers can leverage predictive data to reduce waste and inefficiencies, automate production operations for greater efficiency, and respond quickly to changes in the environment. By taking advantage of IoT-driven technologies, manufacturers can realize greater performance, improved operations, and improved cost savings.

Table 3. Comparison of energy consumption (in %)

No.of rounds	CVIC	MLRA	LMIoT	Proposed
100	83.33	80.26	70.71	81.48
200	83.00	78.76	70.12	79.61
300	81.66	77.65	69.14	78.78
400	80.52	77.27	67.93	77.87
500	79.47	76.26	66.79	76.95

5. Conclusion

Internet of Things (IoT) driven Real-Time Data Collection and Analysis for Lean Manufacturing is an advanced method of Lean Manufacturing, where machinery and operating systems are interconnected with sensors and integrated with advanced software to enable the organization to collect and analyze information in real-time. This data is utilized for automating the process of production, analyzing cost-efficiency, effectively diagnosing equipment status and performance, and minimizing human operator errors. Using IoT-driven data collection and analysis, Lean Manufacturers can improve their operations by providing visibility into production performance, identifying the root causes of inefficiency, and reducing setup times, waste, and defects. In the case of machine automation, the data collected from the sensors can help to monitor and adjust machines to optimize their performance continuously. Automated collection also offers the capability to store, analyze, and share data with stakeholders so that the organization can identify and implement issues quickly.

Additionally, IoT solutions can be utilized to provide structure for implementing quality standards and ensuring compliance. In summary, IoT-Driven Real-Time Data Collection and Analysis for Lean Manufacturing is a powerful tool that allows Lean Manufacturers to improve their processes and operations cost-effectively and efficiently with real-time visibility into production performance, identifying the root causes of inefficiency and reducing setup times, waste, and defects. This data is critical for understanding and improving the production process and allowing optimization of equipment use while ensuring quality and compliance standards are met.

Acknowledgments
Author 1 and Author 2 contributed equally to this work.

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