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Design and Analysis of an Automated IoT System for Data Flow Optimization in Higher Education Institutions

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ABSTRACT

The transformative capacity of the Internet of Things (IoT) has become evident across various sectors. Despite its potential, a discernible hesitancy exists in its adoption within higher education institutions. This research explores the specific advantages and challenges of implementing IoT in the context of higher education, particularly in optimizing data-driven decision-making processes. The approach focuses on creating a comprehensive IoT framework tailored for higher education, encompassing a foundational data warehouse layer, an intermediary application layer for streamlining data, a message broker layer for data orchestration, a granular message consumer layer for data refinement, and a central data lake that consolidates both real-time and structured data. This system adeptly manages a continuous stream of structured and real-time data. With the integration of Kafka and TensorFlow, real-time video streams are processed, providing enhanced security measures for campuses. Biometric devices, strategically positioned, offer detailed data on institutional dynamics, all converging into a central data reservoir. This vast data collection presents profound insights, shaping administrative strategies and improving institutional efficiency. The adoption of IoT in higher education holds vast potential, yet challenges persist. Striking a balance between surveillance and privacy, ensuring data integrity, and navigating the complexities of scalability are vital considerations. However, with careful and strategic implementation, IoT integration can usher in a revolutionary era of data-driven academic operations, enhancing both security and institutional efficiency.

1. INTRODUCTION

In an era marked by rapid technological evolution, the Internet of Things (IoT) stands out as a beacon of transformative potential. It promises a paradigm shift in how devices communicate, interact, and ultimately serve human needs [1]. This interconnected web of devices, spanning from everyday household items to sophisticated industrial machinery, offers unparalleled opportunities across industries. Notably, higher education stands at the cusp of this transformative wave, poised to reap the multifaceted benefits of IoT. Higher education institutions, traditionally viewed as bastions of knowledge and learning, are increasingly being recognized for their role as hubs of innovation and technological advancement. Within this context, the IoT serves as more than just a network of connected devices. It represents a confluence of opportunities to enhance operational efficiency, foster research, improve student experiences, and even redefine pedagogical methodologies. Consider the possibilities: environmental sensors that dynamically adjust classroom conditions based on occupancy and weather, smart ID scanners that not only register student attendance but also provide insights into space utilization and student engagement patterns, and connected laboratory equipment that ensures optimal usage while providing real-time data to researchers [2, 3].

Yet, the journey to fully harness the potential of IoT in higher education is not devoid of challenges. A significant concern arises from the observed disconnect between the vast amounts of data generated by IoT devices and their actual utilization in decision-making processes within institutions. In many academic settings, there is an overwhelming wealth of data being generated, but only a fraction of it is being strategically analyzed and employed. For instance, while a smart device might meticulously track and record student attendance or lab equipment usage, this data often remains siloed, failing to be integrated into a broader analytical framework that could offer insights about student performance, equipment efficiency, or even predictive analytics about future trends. Such a glaring disparity between data availability and its utilization is not just an operational inefficiency; it is a lost opportunity. Institutions that do not leverage this data risk missing out on insights that could drive strategic decisions, optimize resources, and ultimately enhance the overall educational experience [4, 5]. With these considerations in mind, this study delves into the intricacies of designing and implementing an IoT framework specifically tailored to the unique demands and opportunities presented by higher education institutions.

2. MATERIALS AND METHODS

In the initial phase of the study, pivotal departments within a standard higher education institution were delineated. These departments, integral to the institution's operations, encompass the registry, human resources, finance, security, facility management, medical services, and library. Each of these departments generates specific data types, which play a crucial role in the institution's daily operations. Data within the institution can be broadly categorized into dynamic and structured forms. Dynamic data, often termed as streaming or unstructured data, emanates from various sources. Notable examples include video surveillance systems and biometric sensors strategically positioned throughout the institution. In contrast, structured data is derived from the departments and adheres to a predefined schema, reflective of each department's unique operations. To facilitate the establishment of a comprehensive IoT ecosystem, an exhaustive list of essential technologies, software applications, hardware components, storage solutions, and security apparatus was compiled. This list serves as a foundational blueprint for the proposed system. Subsequently, an intricate operational framework was conceptualized. This framework delineates access layers for diverse institutional stakeholders, ensuring stringent measures for access control, data privacy, integration, and security. The system's architecture, which provides a visual representation of data flow and structural components, is illustrated in Figure 1.

In addition, the design of the IoT framework is tailored specifically for the nuanced demands of higher education institutions. Hence, the multi-layered architecture seen in Figure 2 underscores the complexity and sophistication of modern data operations, from data warehousing to message brokering and real-time data processing. The framework focuses on the seamless integration of structured data from diverse institutional departments and real-time streaming data. The methodology employed encompasses the data warehouse layer, application layer, message broker layer, message consumer layer, and the central data lake. Furthermore, the use of Kafka Streams and TensorFlow-backed machine learning models ensures real-time processing and indexing of video streams, emphasizing the framework's commitment to harnessing cutting-edge technologies. The data flow within this framework is methodically optimized. It starts from structured data housed within various departments, which are then meticulously pushed to the message queuing service. This transition ensures the importance of real-time data processing in the IoT paradigm. The Message Queue Infrastructure acts as a bridge, ensuring a seamless transmission of data. The dual-feed mechanism of the Data Lake emphasizes its versatility in handling both structured and real-time data.

The sanctity of personal data, especially when dealing with biometric and surveillance data, is paramount. As the data volume increases, there is an implicit need for robust data governance frameworks, to ensure data integrity and security. The system prioritizes safeguarding this "new gold," especially given the integrated nature of the system, which can make it more vulnerable to breaches if security protocols are not rigorously updated. In addition to comprehensive surveillance, the system requires stringent privacy safeguards. Balancing the need for this comprehensive data collection with the imperative for individual privacy is crucial. Ensuring continuous training and updating of machine learning models to minimize false positives, coupled with robust data governance frameworks, is paramount in upholding data sanctity and privacy.

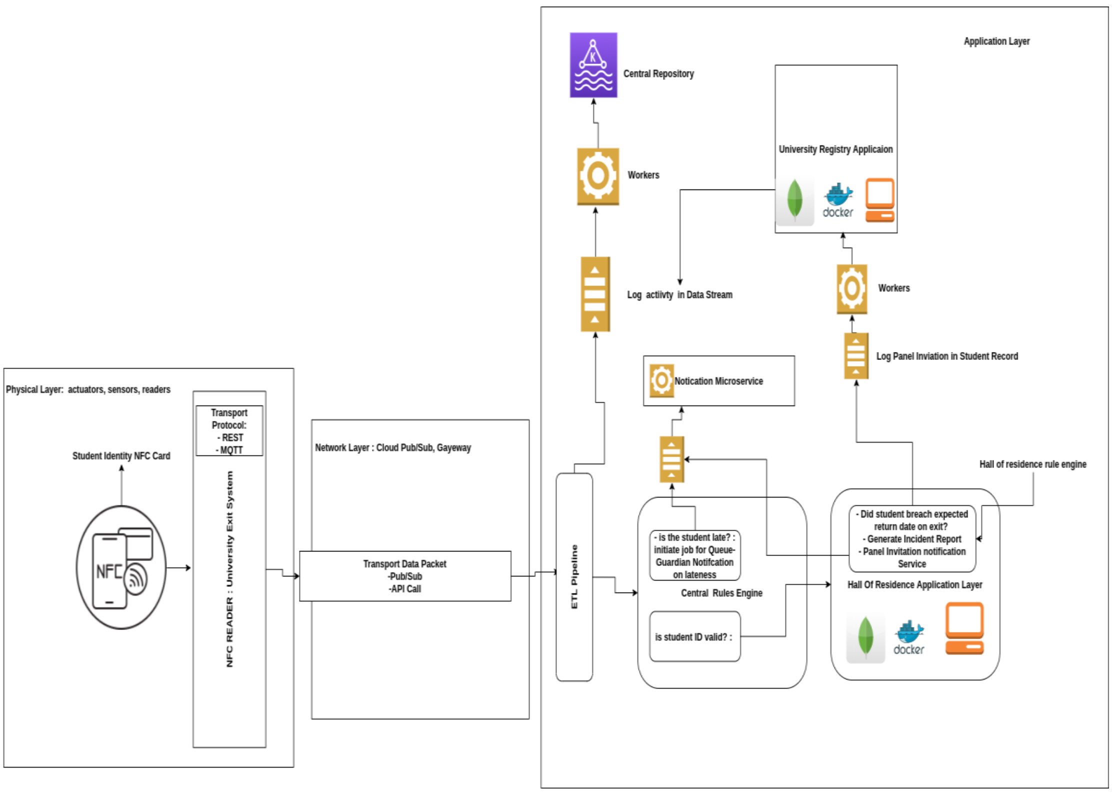

Figure 1. IoT architecture layer and data pipeline

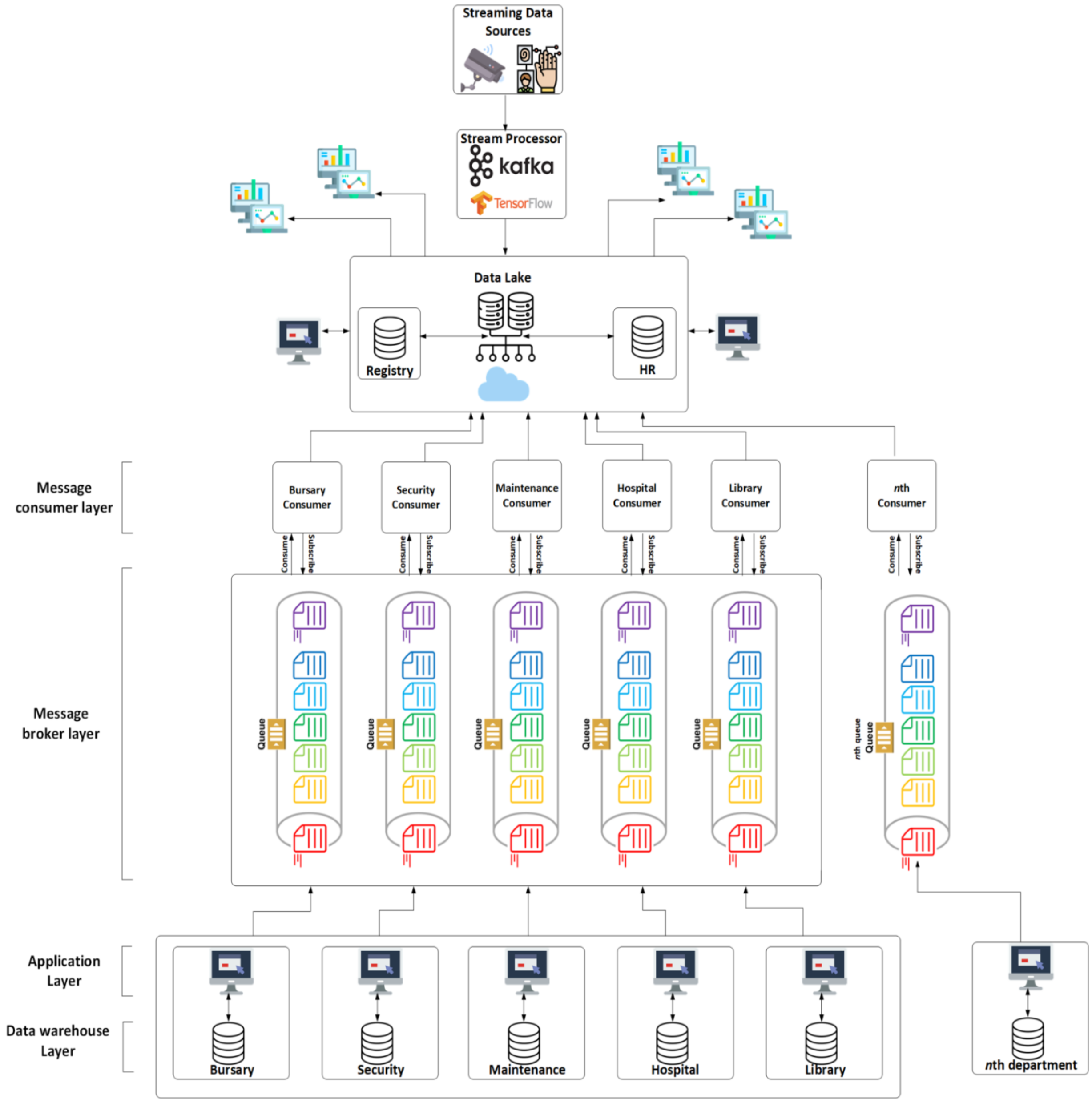

Figure 2. IoT framework

3. THEORY

IoT represents a paradigm shift in the way devices communicate. It's not just about connecting devices to the Internet, but about creating a vast, interconnected ecosystem where devices, from the most mundane to the most sophisticated, can communicate, share data, and make autonomous decisions based on shared insights [6-9]. In the realm of business, this has profound implications. Real-time data analysis, facilitated by IoT, provides businesses with unparalleled insights into their operations, customer preferences, and market trends. This, in turn, allows for agile decision-making, predictive analysis, and proactive problem-solving. Industries spanning from agriculture to retail are harnessing the power of IoT to revolutionize their operations, offering enhanced services and products to their customers [6].

Figure 3 portrays the progressive trajectory of IoT technology, mapping its evolution from foundational implementations to its current advanced state. It effectively captures distinct milestones, emphasizing seminal technological breakthroughs that have continually refined IoT's capabilities. These epochs span from the inception of rudimentary systems, such as RFID-based inventory management, to the integration of cutting-edge AI and machine learning algorithms in contemporary IoT ecosystems. A notable aspect is the showcase of the expansion of IoT across diverse sectors, reflecting its transition from specialized applications to pervasive implementations in industries ranging from healthcare to urban planning. Furthermore, the figure underscores the symbiotic relationship between IoT and other emergent technologies, highlighting the confluence of IoT with paradigms like cloud computing, big data analytics, and advanced cybersecurity measures. In essence, Figure 3 encapsulates the monumental journey of IoT, emphasizing its transformative impact on the global technological landscape. Providing profound evidence as to how this can also benefit institutions of higher learning [10]. This progression is not just a technological marvel but holds significant implications for higher education institutions. In the academic environment, IoT devices could range from smart ID scanners registering student attendance, sensors in labs monitoring equipment usage, to environmental sensors overseeing campus conditions. The expansion of IoT across sectors, from healthcare to urban planning, reflects its potential to transform higher education, moving from specialized applications to pervasive implementations within campuses.

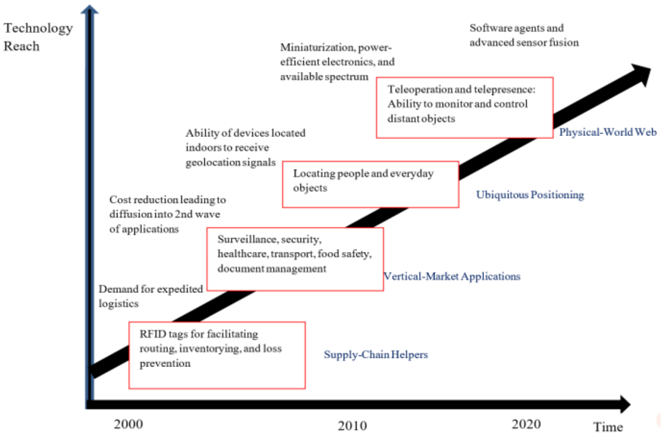

Figure 3. Technology growth strategy for the Internet of Things [10]

3.1 Elements of IoT

IoT is a symphony of interconnected components working in harmony. These components range from tangible hardware like sensors and actuators to intangible middleware like databases and analytical tools. The success of an IoT system hinges on the seamless integration of these components. Furthermore, each device within this network requires a unique identifier, ensuring precise data collection and communication. The amalgamation of sensing mechanisms, communication protocols, and data analytics tools ensures that the system is not only efficient but also insightful [11-13]. At its core, IoT is a fusion of hardware and software, working seamlessly to capture, transmit, and process data. Figure 1 shows that the Physical (Perception) Layer serves as the foundation, where physical devices like sensors incessantly capture real-world data. This could be smart devices in classrooms or security cameras around the campus. The Network Layer acts as the conduit, transmitting the captured data for further processing. It ensures data integrity, timely delivery, and efficient routing. The Application Layer is where raw data is transformed into actionable insights. In academic institutions, this layer could provide real-time analytics on student performance or predictive maintenance alerts for campus infrastructure. The integration of technologies like Kafka for real-time data processing and TensorFlow for machine learning amplifies the potential of IoT in higher education. This interrelation of elements underpins the potential of IoT to revolutionize higher education, enhancing campus operations, security protocols, and data-driven decision-making.

3.2 Key features of IoT

The modern interpretation of IoT is a culmination of years of technological advancements. Its current form, characterized by features such as artificial intelligence, enhanced connectivity, and miniaturized yet powerful sensors, is a testament to the rapid pace of innovation in this field [14-16]. The applications of IoT are vast and varied, from optimizing customer interactions to refining technological processes, reducing waste, and facilitating comprehensive data collection. However, the journey of IoT is not without its challenges. As the network grows, so do concerns about security, privacy, and the complexities of managing such a vast interconnected system [17-22].

3.3 Popular applications of IoT and industrial benefits

IoT is used in nearly all aspects of life as we know it. These applications cut across virtually all the industries in operation today. The popular applications of IoT include smart homes, smart cities, self-driven cars, IoT retail shops, smart farms, wearables, smart grids, industrial Internet, digital health, and smart supply-chain management [21, 23-27]. Organizations that would profit from utilizing sensor devices, among other things, in their business operations are the ideal candidates for IoT. Such industries include manufacturing, automotive, transportation and logistics, retail, public sector, and healthcare [28-31].

3.3 Business impacts of IoT

The integration of IoT into the business landscape is reshaping traditional operational models and strategies. As organizations grapple with the challenges and opportunities presented by this technological revolution, it becomes evident that IoT is not just a tool but a transformative force [32-34]. For businesses, the primary allure of IoT lies in its ability to provide real-time, actionable insights. These insights, derived from a myriad of interconnected devices and sensors, offer a granular view of operations, customer preferences, and market dynamics. This level of detail, previously unattainable, allows businesses to pivot rapidly, capitalizing on emerging trends and addressing inefficiencies proactively.

Moreover, the versatility of IoT means that its applications are not confined to a single sector or function. From supply chain optimization, where IoT can track and predict inventory needs, to customer engagement, where personalized experiences can be crafted based on user data, the possibilities are vast. This multifaceted approach ensures that businesses can derive value at multiple touchpoints, enhancing both their operational efficiency and customer value proposition. However, the transformative potential of IoT extends beyond mere operational enhancements. It offers businesses the opportunity to rethink and reinvent their core strategies. Traditional product-based companies, for instance, can transition to service-based models, leveraging IoT's continuous data stream to offer value-added services. Conversely, service-based entities can integrate IoT-enabled products to diversify their offerings [35-37].

In the realm of higher education institutions, the implications are profound. Imagine a campus where every device, from lighting systems to lecture halls, is interconnected. Such a system could monitor and optimize energy consumption, enhance security through real-time surveillance, and even predict and address maintenance issues before they escalate. Furthermore, on the academic front, IoT can provide insights into student engagement, attendance patterns, and resource utilization. This data, when analyzed, can inform curriculum design, teaching methodologies, and even student well-being initiatives. In conclusion, while the journey of integrating IoT is fraught with challenges, from security concerns to implementation complexities, the potential rewards far outweigh the risks. As businesses and institutions navigate this new frontier, a paradigm shift in strategy, operations, and value creation is imminent.

3.5 Challenges and limitations of IoT in higher education

While the transformative potential of IoT in the academic sector is vast, the journey to integration is not without challenges. Scalability remains a concern as institutions grow and evolve, increasing the number of devices and data volume. The more integrated the system, the greater the vulnerability to potential breaches, especially if security protocols are not rigorously updated. There is also the challenge of interoperability, where different devices, software solutions, and platforms may not communicate seamlessly. Implementing and maintaining such systems requires not only financial investment but also expertise. Ensuring consistent interoperability, especially in an environment as diverse as higher education, can be daunting. It is crucial for institutional decision-makers to weigh these challenges against the potential benefits.

4. SYSTEM ARCHITECTURE AND DESIGN

The integration of IoT within enterprise systems necessitates a robust and scalable architecture, given the data-intensive nature of IoT platforms. The architecture must ensure seamless data communication across all layers, from perception to application, while also accommodating the unique requirements of IoT applications. This section delves into the intricacies of designing such an architecture, emphasizing the pivotal role of the application layer and the integration of specific design patterns and pipelines to optimize data flow.

4.1 Layered approach to IoT architecture

The IoT architecture can be visualized as a three-tiered structure comprising the Perception, Network, and Application layers:

a. Perception Layer: Serving as the foundation of the IoT ecosystem, the Perception Layer epitomizes the physical realm where a plethora of sensors and IoT devices incessantly capture real-world data. In the academic environment, this might encompass devices like smart ID scanners that register student attendance, sensors in labs to monitor equipment usage, or environmental sensors to oversee campus conditions.

b. Network Layer: Acting as the conduit between the physical and digital realms, the Network Layer undertakes the paramount task of transmitting the captured data from the Perception Layer to the Application Layer. It is this layer that ensures data integrity, timely delivery, and efficient routing. Within a higher education context, this layer could be handling data traffic from thousands of devices simultaneously, from classroom smart devices to security cameras.

c. Application Layer: Undoubtedly the nerve center of the IoT framework, the Application Layer processes, analyzes, and translates raw data into actionable insights. It is within this layer that the strategic value of data is truly harnessed. In academic institutions, this layer could provide real-time analytics on student performance, predictive maintenance alerts for campus infrastructure, or even insights into optimizing energy usage across various campus facilities.

4.2 ETL pipeline integration

IoT in higher education presents a unique challenge. It entails handling a deluge of continuous data streaming from myriad devices. The ETL (Extract, Transform, Load) pipeline, as illustrated in Figure 1, offers a structured approach. Data is 'extracted' in real-time from diverse sources (like student devices, lab equipment, or library systems), 'transformed' into a consistent and usable format (perhaps consolidating data or converting it into a standard schema), and then 'loaded' into the Application Layer for further analysis. In the context of higher education, this could mean aggregating data from various departments to gain comprehensive insights or streamlining data from online learning platforms to assess student engagement.

4.3 Rules engine design pattern

Enterprise systems, by their very nature, are governed by a plethora of rules, policies, and conditions. In an IoT framework, these rules play a crucial role in determining how data is processed and analyzed. The Rules Engine Design Pattern offers a solution, allowing for the dynamic implementation of organizational policies within the system. By integrating a rules engine:

a. Boundaries are established, segregating the roles and responsibilities of different stakeholders within the application layer.

b. Data processing is streamlined, with each stakeholder processing data based on predefined rules and conditions.

c. Flexibility is enhanced, as rules can be modified or updated without disrupting the system's overall functionality.

Suffice it to say that the architecture and design of an IoT system, especially within the context of higher education institutions, must be both robust and flexible. By integrating the ETL pipeline with the Rules Engine Design Pattern, this research offers a blueprint for building scalable and efficient IoT platforms, as depicted in Figure 1. The vast expanse of data within an academic institution necessitates governance. The Rules Engine Design Pattern, integrated within the architecture, dynamically enforces institutional policies, regulations, and conditions. It automates decision-making based on predefined criteria. For instance, if a sensor in a lab detects equipment being used after hours, the Rules Engine could cross-reference this with staff and student access permissions, triggering relevant alerts or actions.

The system architecture and design offer a thorough overview of the system's components, their interplay, and the inherent challenges. It underscores the significance of the ETL pipeline and rules engine design pattern in the unique context of higher education while also candidly addressing the potential pitfalls and challenges that institutions might face in the system's real-world implementation.

5. RESULTS AND DISCUSSION

The integration of IoT in higher education institutions has paved the way for a transformative approach to data collection, analysis, and decision-making. The ability to harness vast amounts of data from various sources, both structured and unstructured, offers institutions a unique opportunity to optimize operations, enhance security, and improve the overall campus experience. The IoT framework for higher education institutions has shown tremendous potential in harnessing and interpreting vast datasets. Leveraging advanced analytics tools and sophisticated algorithms, the system processes the indexed data to derive actionable insights. For instance, using machine learning models, patterns in student attendance, equipment usage, and energy consumption have been discerned. These patterns not only facilitate real-time decision-making but also predict future trends. Techniques like clustering have been employed to segment student populations based on various metrics, while regression analysis has helped in understanding correlations, such as between student attendance and academic performance.

5.1 Processing and indexing streaming data

The system's capability to process unstructured streaming data was demonstrated through the integration of Kafka Streams, a streaming API based on Apache Kafka. Video streams from cameras across the campus were processed using a machine learning model developed on TensorFlow. This model was trained using images of students and staff, enabling real-time identification. Notably, any unrecognized individuals captured by the cameras were categorized as new entries. Their images, along with the timestamp of their capture, were indexed in the central data lake. This indexing facilitated subsequent queries, providing insights into the movements and activities of all individuals, whether they were students, staff, or visitors.

5.2 Biometric authentication and data indexing

Biometric devices, primarily fingerprint scanners, were strategically placed across the campus. These devices authenticated students and staff, granting them access to specific areas such as offices, the cafeteria, and the library. Every authentication event, including the individual's identity, location, and timestamp, was indexed in the data lake. This data provided a comprehensive view of the daily activities and movements of the campus population. Given the sensitivity of biometric data, stringent measures have been implemented to safeguard it. Data encryption techniques ensure that the data, when stored or transmitted, remains inaccessible to unauthorized entities. Regular security audits are conducted to identify and rectify potential vulnerabilities. Additionally, data anonymization techniques are employed to ensure that the data, even if accessed, cannot be traced back to individual students or staff. The institution also adheres to global data privacy standards, ensuring that personal data is not misused or mishandled.

5.3 Structured data from key departments

Structured data, characterized by a predefined schema, was sourced from pivotal departments within the institution, as illustrated in Figure 2. Each department's data was ingested into the central data lake through a message queuing mechanism, ensuring a seamless and decoupled data flow. The data lake, serving as the system's core, indexed data based on departmental operations. For instance, health records from the campus hospital were indexed to provide insights into the health status and medical history of students and staff.

5.4 Deriving insights from indexed data

The indexed data in the data lake was a treasure trove of information, offering a plethora of insights into the operations of each department and the overall functioning of the institution. Several scenarios highlighted the system's potential:

a. Analyzing staff attendance patterns could reveal trends, such as a staff member consistently missing work on specific days.

b. Video footage could provide evidence of misconduct, leading to disciplinary actions against students.

c. Visitor patterns could be analyzed to identify regular visitors and their frequency of visits.

These insights, derived from the comprehensive data framework depicted in Figure 2, empowered the institution's administration to make informed decisions. The entire data flow and system operations are visualized in Figure 4, providing a holistic view of the integrated IoT system.

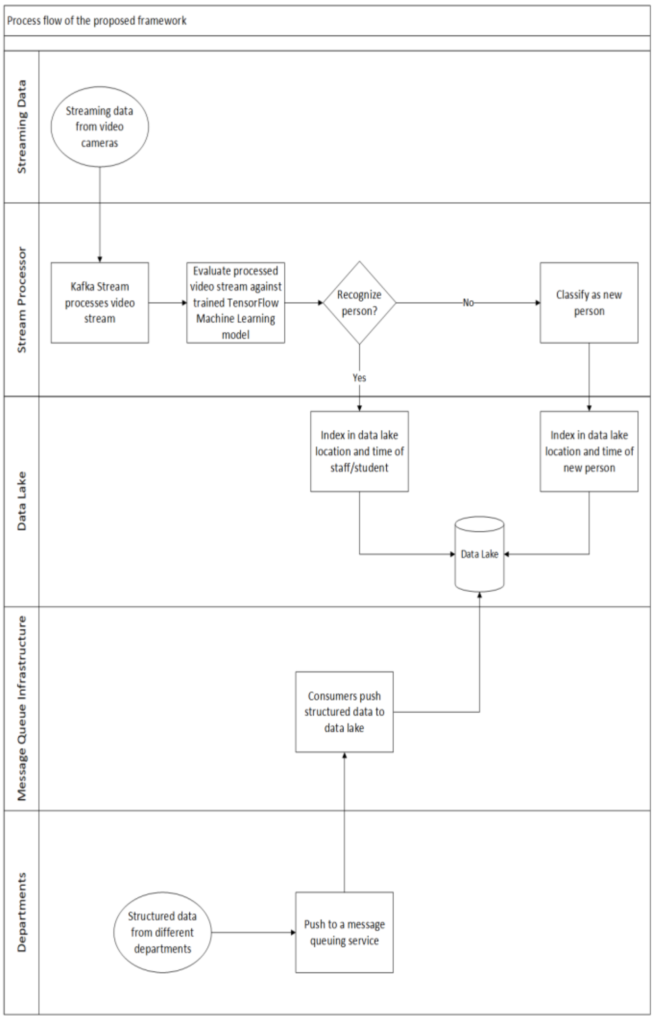

Figure 4. Process flow of the proposed system

5.5 Anticipated advancements and prospective real-world scenarios

The anticipated deployment of the IoT framework within the institution is expected to usher in a plethora of tangible and quantifiable enhancements, sculpting a future-forward and agile educational ambiance.

Smart ID Scanners and Attendance Dynamics: A pivotal transition foreseen with the implementation of the IoT framework is the introduction of Smart ID scanners across the campus. Conventional attendance mechanisms, which are manual and prone to inaccuracies, will likely become obsolete. Students will be able to swiftly scan their IDs upon entering lecture halls or labs, with their attendance instantly and accurately recorded. This streamlined process is predicted to dramatically reduce instances of proxy attendance. The system's capability to instantaneously cross-verify the scanned data with the student's biometric database will ensure an authentic attendance record, deterring any attendance misrepresentation. This refined approach will provide instructors with a clearer and more accurate attendance landscape, aiding them in offering targeted support to students who might demonstrate irregular attendance patterns.

Optimization of Lab Equipment Usage: One of the pressing challenges that institutions often face revolves around maximizing the utilization of laboratory equipment. With the proposed IoT system's capability to monitor equipment usage in an uninterrupted manner, a transformative reshaping of lab reservation methodologies is anticipated. By analyzing equipment usage patterns, peak demand times, and potential equipment malfunction trends, it is foreseen that lab schedules and maintenance protocols will undergo a significant overhaul. Such data-driven restructuring is expected to yield a 20% surge in equipment accessibility, ensuring students benefit from enhanced equipment availability. Moreover, the proactive maintenance insights derived from the system will likely curtail equipment downtime, fostering smoother and more efficient lab operations.

Energy Efficiency Through Environmental Sensors: A potential game-changer in campus sustainability is the envisioned integration of environmental sensors. These sensors, when strategically positioned, are anticipated to continuously assess parameters like ambient temperature, humidity levels, and prevalent lighting conditions. The collated data will then interface with the central IoT system, which in turn will orchestrate real-time optimizations of the Heating, Ventilation, and Air Conditioning (HVAC) infrastructure. For instance, on days forecasted to be cooler, the system might proactively modulate heating levels in less populated zones of the campus or regulate lighting based on predicted sunlight exposure. Such automated calibrations are projected to cumulatively result in a 15% reduction in energy expenditures. This anticipated energy conservation not only signifies prospective financial savings but also amplifies the institution's commitment to ecological preservation and sustainability.

5.6 Implications and future prospects

The results underscore the transformative potential of IoT in higher education. By harnessing real-time data, institutions can proactively address security concerns, optimize resource allocation, and enhance the student and staff experience. Moreover, the ability to analyze patterns and trends can inform strategic planning, leading to more efficient and effective institutional operations. While the current results are promising, the journey towards complete IoT integration in higher education has just begun. The potential for incorporating augmented reality in classrooms, using deep learning models for administrative tasks, and virtual reality for experimental simulations is vast. However, with advancements come challenges. The growing number of devices and the consequent data explosion will demand more robust data management systems. Ensuring data privacy, especially with the increasing integration of biometric devices, will be paramount. Interoperability, given the pace of technological advancements, will be another area requiring constant attention.

6. CONCLUSIONS

This research study accentuates the transformative potential of the Internet of Things (IoT) within higher education. This study’s prime contribution lies in its tailored IoT framework for educational institutions, offering a synergy of real-time data acquisition, advanced analytics, and actionable insights. The design incorporates elements like Kafka Stream and Data Lake, poised to redefine institutional dynamics. In the anticipated outcomes, the system is expected to manifest a profound impact. Foreseen enhancements encompass better optimization of lab equipment access and significant energy savings via intelligent HVAC systems. Such results will underscore the system's potential to foster a secure, data-centric campus ambiance, enriched by capabilities like instantaneous surveillance and biometric-based attendance tracking. However, potential challenges arise with such advancements. Scalability and data demands necessitate continuous architectural refinements. Concerns related to data privacy, security, and governance become paramount as data integration increases. As IoT interlaces with technologies like augmented reality and machine learning, the system must remain adaptable. Lastly, this research serves as a guide for institutions navigating technological integration. The fusion of education with IoT, as presented, suggests a future where institutions become hubs of innovation and data-driven decision-making, promising an efficient and evolved academic landscape.

REFERENCES

[1] Tiwary, A., Mahato, M., Chidar, A., Chandrol, M.K., Shrivastava, M., Tripathi, M. (2018). Internet of Things (IoT): Research, architectures and applications. International Journal on Future Revolution in Computer Science & Communication Engineering, 4(3): 23-27.

[2] Aldowah, H., Rehman, S.U., Ghazal, S., Umar, I.N. (2017). Internet of Things in higher education: A study on future learning. In Journal of Physics: Conference Series, 892(1): 012017. https://doi.org/10.1088/1742-6596/892/1/012017

[3] Angelova, N., Kiryakova, G., Yordanova, L. (2017). The great impact of Internet of Things on business. Trakia Journal of Sciences, 15(1): 406-412. https://doi.org/10.15547/tjs.2017.s.01.068

[4] Boca, L.L., Ciortea, E.M., Boghean, C., Begov-Ungur, A., Boghean, F., Dădârlat, V.T. (2023). An IoT system proposed for higher education: Approaches and challenges in economics, computational linguistics, and engineering. Sensors, 23(14): 6272. https://doi.org/10.3390/s23146272

[5] Kumar, S., Tiwari, P., Zymbler, M. (2019). Internet of Things is a revolutionary approach for future technology enhancement: A review. Journal of Big data, 6(1): 1-21.

https://doi.org/10.1186/s40537-019-0268-2
[6] Lee, I., Lee, K. (2015). The Internet of Things (IoT): Applications, investments, and challenges for enterprises. Business Horizons, 58(4): 431-440. https://doi.org/10.1016/j.bushor.2015.03.008
[7] Madakam, S., Lake, V., Lake, V., Lake, V. (2015). Internet of Things (IoT): A literature review. Journal of Computer and Communications, 3(5): 56616. https://doi.org/10.4236/jcc.2015.35021
[8] Chen, S., Xu, H., Liu, D., Hu, B., Wang, H. (2014). A vision of IoT: Applications, challenges, and opportunities with china perspective. IEEE Internet of Things Journal, 1(4): 349-359. https://doi.org/10.1109/JIOT.2014.2337336
[9] Xhafa, F. (2019). Special issue "Internet of Things (IoT)-based Services". Computing, 101: 725–727. https://doi.org/10.1007/s00607-019-00719-2
[10] Tohanean, D., Vasilescu, A. (2019). Business models and Internet of Things. Proceedings of the International Conference on Business Excellence, 13(1): 1192–1203. https://doi.org/10.2478/picbe-2019-0105
[11] Patel, K.K., Patel, S.M., Scholar, P. (2016). Internet of Things-IoT: Definition, characteristics, architecture, enabling technologies, application & future challenges. International Journal of Engineering Science and Computing, 6(5): 6122–6131.
[12] Farooq, M.U., Waseem, M., Mazhar, S., Khairi, A., Kamal, T. (2015). A review on Internet of Things (IoT). International Journal of Computer Applications, 113(1): 1-7.
[13] Gubbi, J., Buyya, R., Marusic, S., Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems, 29(7): 1645-1660. https://doi.org/10.1016/j.future.2013.01.010
[14] Burhanuddin, M.A., Mohammed, A.A.J., Ismail, R., Hameed, M.E., Kareem, A.N., Basiron, H. (2018). A review on security challenges and features in wireless sensor networks: IoT perspective. Journal of Telecommunication, Electronic and Computer Engineering (JTEC), 10(1-7): 17-21. https://jtec.utem.edu.my/jtec/article/view/3589
[15] Yassein, M.B., Aljawarneh, S., Al-Sadi, A. (2017). Challenges and features of IoT communications in 5G networks. In 2017 International Conference on Electrical and Computing Technologies and Applications (ICECTA), pp. 1-5. https://doi.org/10.1109/ICECTA.2017.8251989
[16] Formisano, C., Pavia, D., Gurgen, L., Yonezawa, T., Galache, J.A., Doguchi, K., Matranga, I. (2015). The advantages of IoT and cloud applied to smart cities. In 2015 3rd International Conference on Future Internet of Things and Cloud, pp. 325–332. https://doi.org/10.1109/FiCloud.2015.85
[17] Bayani, M., Leiton, K., Loaiza, M. (2017). Internet of Things (IoT) advantages on E-learning in the smart cities. International Journal of Development Research, 7(12): 17747-17753.
[18] Grammatikis, P.I.R., Sarigiannidis, P.G., Moscholios, I.D. (2019). Securing the Internet of Things: Challenges, threats and solutions. Internet of Things, 5: 41-70. https://doi.org/10.1016/j.iot.2018.11.003
[19] Balaji, S., Nathani, K., Santhakumar, R. (2019). IoT technology, applications and challenges: A contemporary survey. Wireless Personal Communications, 108: 363-388. https://doi.org/10.1007/s11277-019-06407-w
[20] Bhayani, M., Patel, M., Bhatt, C. (2016). Internet of Things (IoT): In a way of smart world. In Proceedings of the International Congress on Information and Communication Technology: ICICT 2015, pp. 343-350. https://doi.org/10.1007/978-981-10-0767-5_37
[21] Soumyalatha, S.G.H. (2016). Study of IoT: Understanding IoT architecture, applications, issues and challenges. In 1st International Conference on Innovations in Computing & Networking (ICICN16), CSE, RRCE. International Journal of Advanced Networking & Applications, pp. 477-482.
[22] Cvitić, I., Vujić, M. (2015). Classification of security risks in the IoT environment. 26th DAAAM International Symposium On Intelligent Manufacturing And Automation, 26(1): 731-740.
[23] Kiran, S., Sriramoju, S.B. (2018). A study on the applications of IoT. Indian Journal of Public Health Research & Development, 9(11).
[24] Pawar, A.B., Ghumbre, S. (2016). A survey on IoT applications, security challenges and counter measures. In 2016 international conference on computing, analytics and security trends (CAST), pp. 294-299. https://doi.org/10.1109/CAST.2016.7914983
[25] Bessis, N., Xhafa, F., Varvarigou, D., Hill, R., Li, M. (2013). Internet of Things and inter-cooperative computational technologies for collective intelligence. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-34952-2
[26] Mocrii, D., Chen, Y., Musilek, P. (2018). IoT-based smart homes: A review of system architecture, software, communications, privacy and security. Internet of Things, 1: 81-98. https://doi.org/10.1016/j.iot.2018.08.009
[27] Sun, Y., Song, H., Jara, A.J., Bie, R. (2016). Internet of Things and big data analytics for smart and connected communities. IEEE Access, 4: 766-773. https://doi.org/10.1109/ACCESS.2016.2529723
[28] Ghanbari, A., Laya, A., Alonso-Zarate, J., Markendahl, J. (2017). Business development in the Internet of Things: A matter of vertical cooperation. IEEE Communications Magazine, 55(2): 135-141. https://doi.org/10.1109/MCOM.2017.1600596CM
[29] Kumar, A.S., Iyer, E. (2019). An industrial IoT in engineering and manufacturing industries—benefits and challenges. International Journal of Mechanical and Production Engineering Research and Dvelopment (IJMPERD), 9(2): 151-160. http://doi.org/10.24247/ijmperdapr201914
[30] Xu, L.D., He, W., Li, S. (2014). Internet of Things in industries: A survey. IEEE Transactions on Industrial Informatics, 10(4): 2233-2243. https://doi.org/10.1109/TII.2014.2300753
[31] Sri, K.S., Krishna, K.V.S.S.R., Madamanchi, V.B.R., Devi, G.Y. (2021). Advanced system control with traffic handling for secure communication in IoT routing protocol. Journal Européen des Systèmes Automatisés, 54(2): 229-233. https://doi.org/10.18280/jesa.540204
[32] Razooqi, R.A., Hassan, H.J., Saheb, G.M.A. (2022). Selection algorithm for reducing IoT service delay in the smart factory. Journal Européen des Systèmes Automatisés, 55(3): 419-426. https://doi.org/10.18280/jesa.550315

[33] Del Giudice, M. (2016). Discovering the Internet of Things (IoT): Technology and business process management, inside and outside the innovative firms. Business Process Management Journal, 22(2). https://doi.org/10.1108/BPMJ-02-2016-0029

[34] Mohammed, N.A., Abdulateef, O.F., Hamad, A.H. (2023). An IoT and machine learning-based predictive maintenance system for electrical motors. Journal Européen des Systèmes Automatisés, 56(4): 651-656. https://doi.org/10.18280/jesa.560414

[35] Yerpude, S., Singhal, T.K. (2017). Internet of Things and its impact on Business Analytics. Indian Journal of Science and Technology, 10(5): 1-6.

[36] Leminen, S., Westerlund, M., Rajahonka, M., Siuruainen, R. (2012). Towards IoT ecosystems and business models. In Conference on Internet of Things and Smart Spaces, pp. 15-26. https://doi.org/10.1007/978-3-642-32686-8_2

[37] Murthy, D.N., Kumar, B.V. (2015). Internet of Things (IoT): Is IoT a disruptive technology or a disruptive business model? Indian Journal of Marketing, 45(8): 18-27. http://doi.org/10.17010/ijom/2015/v45/i8/79915