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Integrating IoT devices in Clinical Laboratories for Real-time Monitoring

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Abstract

Using Internet of Things (IoT) devices in clinical labs has become a ground-breaking strategy to transform conventional laboratory management. The main factors and procedures for deploying IoT technology for real-time monitoring in healthcare settings are described in this research. Labs may get more efficiency, accuracy, and data-driven decision-making by defining crucial integration areas, choosing appropriate equipment, and guaranteeing connectivity and security procedures. In order to protect patient data, the article stresses the significance of seamless integration with current Laboratory Information Management Systems (LIMS) and adherence to healthcare legislation. For measuring the research used SPSS software and generate result included correlation, regression analysis, the chi square analysis between them. Laboratory workers are empowered to react quickly to abnormalities by means of an intuitive real-time monitoring dashboard, remote access features, and proactive alerts, which save downtime and enhance overall operational procedures. The topic of power management systems, scalability, and the requirement for feedback loops to facilitate ongoing development are also covered. Laboratory staff adoption of IoT technology is facilitated by the implementation of training programmes and change management techniques. Overall result founded that, integrating IoT devices into clinical laboratories offers a revolutionary approach that improves patient care outcomes while offering real-time insights into crucial parameters. A dedication to continuous development guarantees the continual optimisation of IoT systems as laboratories adopt this technological transformation, promoting a more responsive and networked healthcare environment.

Keywords: Integrating IOT devices (IOT), Clinical Laboratories (CL), Real-Time Monitoring (RTM).

Introduction

The term "IoT devices" can be explained in these words "Internet of things which are webbed or connected with devices such as any sensors, any kind of software or any type of other technology to share and exchange different types of data from one device to other with the help of internet ". There are different examples of IoT devices such as different smart thermostats, trackers for activity, different robots, and others [1]. As we all know science and technology have made tremendous achievements in each facet of life ranging from individual level to social level. In this study, we are going to overview how Integrating IoT devices can be used for laboratory purposes in real-time monitoring. The term real-time monitoring can be enumerated as a kind of advanced technology that allows to analysis of the current situation of different channels in any organization[2].

Nowadays the Internet of Things which is abbreviated as IoT plays a very important role in the health sector and is also important for the betterment of the health condition of patients. It helps in better interaction of physician with the patient and can also increase the rate of swift response of physician to patient [3]. Now portable IoT-based sensors are mostly used in laboratories for the diagnosis and detection of different diseases in a short time [4]. Different IoT-based sensors are named telemedicine, remote type scanning, the remote monitoring of patients, the swift and accurate management of samples, different clinical operations, and increasing Workflow management[5]. Now these IoT-based systems are mostly portable and wearable for example smart wristbands that can monitor heart rate, blood pressure, sugar level, and others in very little time. In this kind of wearable technology, recorders are installed that can receive electric signals from the body for the detection of particular factors. These remote monitoring systems enable a person to communicate with clinicians and physicians through video calls, email, and others through which they can get better guidance in a short time increasing the efficiency of the Healthcare system[6]. One of the IoT-based devices that is mostly used in the laboratory is an automated microscope which can be easily used for imaging different cells, and analyzing, and integrating data related to normal and pathogenic cells. These types of microscopes are better as compared to traditional compound microscopes because these microscopes do not need slide preparation and can perform repetitive analysis in a short time. Because these types of microscopes are fully automated thus they do not need human assistance for better work[7].

These types of microscopes can produce whole slide imaging which provides information in the form of single-knitted images for diagnosis of different diseases such as cancer by using automated microscopes. The other IoT-based device is the autoclave, which is a kind of machine that operates under high pressure to kill germs such as bacteria, fungi, viruses, and others. This technique can be used for sterilization of laboratory instruments which increases the chances for accurate results and decreases the risk of error in laboratory results[8]. It is also better than previous sterilization methods because it is fully automated and does not need manual sterilization. There are various types of automated sensors are used in laboratories nowadays such as temperature sensors, humidity sensors, pressure sensors, and others. These temperature sensors are fully automated and computerized can measure temperature in a short time and can give data in digital form that can easily be analyzed and integrated[9].

The other important IoT-based system that is used in clinical laboratories is auto sample which is an automated system to continuously provide samples to instruments for better analysis. The other IoT-based system that is commonly used in laboratories is

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electronic data storage in which data is not stored manually rather it is stored in the form of electric signals in small chips called microchips. This system of data collection and storage is quite reliable than traditional methods because there is very little risk of data loss in this type of data storage system[10].

These types of data storage provide reliable and easily accessible methods for analyzing the results of laboratory tests. The other very beneficial IoT-based device that is frequently used in clinical laboratories is liquid handling robots which are automated pipettes that can transport very precise and small volumes of liquids during laboratory testing systems. Some different types of robots can sort different test tubes in the laboratory, which can help in laboratory management and thus increase the Workflow from laboratories.

Nowadays such robots are also made that can perform few experiments independently and can also analyze these results without the help of any human intelligence[11]. Not only this but few robots are designed to transfer test tubes from ward to lab which decreases the risk of sample loss or the contamination of sample by other factors. The other example of an automated system in the laboratory is an automated conveyor system which can handle apparatus from one place to another in a fully automated way, such systems are also able to integrate and count the type and number of particular apparatus in the laboratory.

Machine vision is also an IoT-based device in the laboratory in which different computer-based systems are employed as video cameras or monitoring devices that can detect any particular change in a specific sample at any time in the laboratory in a swift way[12]. This study has effectively explained the benefits related to the use of IoT-based systems in laboratories as it reduces cost, shows improved management, less dependence on human labor, fully automated systems, less risk of error, and swift responses for better Workflow from laboratories. However, there are also some problems associated with the increased use of IoT devices in the laboratory [13].

The first problem is that it is dependent upon computerized systems, which can decrease the chance of human error but can increase the risk of instrumental error or computer error. Secondly, it has been highly costly until now and is quite obstructing the way to its proper implementation. Thirdly, it is creating more dependence upon machinery which is creating unemployment in every society on an international level[14].

Research Objective

The main objective of this study is to understand the use of IoT-based devices in Clinical Laboratories for the betterment of the Healthcare sector. This study has effectively explained the benefits and drawbacks related to increasing the use of IT-based systems in the laboratory. The research determines that Integrating IoT devices in Clinical Laboratories for Real-time Monitoring. The research study divided into five sections first portion represent that introduction related to the IOT and Clinical Laboratories this section also present objective of research.

The second section present literature review the third section describe those methods of research also present features of research. The fourth section present result and its descriptions the last portion summarized overall research study and present recommendations about future research.

Literature Review

With the instant rise in maintaining health and fitness during these years, the idea of always having real-time monitoring of the body's vitals has been gaining much attention. Therefore, the concept of the Internet of Things (IoT) has worked wonders in connecting health professionals, medical sensors, and devices to provide valuable medical services in isolated locations of patients[15]. Researchers have shown their interest in developing wearables specifically for elderly people, who become more susceptible to chronic diseases with t age and need a constant point-of-care diagnosis to keep check and balance among their diseases and body regulations[7].

The management of chronic diseases is of serious concern these days as these diseases require constant monitoring at healthcare centers. Therefore, the incorporation of wearable sensors that can monitor the health of patients can be beneficial. Researchers have shown the benefits of connecting mobile applications with health monitoring sensors and devices to make patients and healthcare providers comfortable with their shifts and remote treatments can be made possible[16].

Another study has revealed the outcome of using intelligent sensors for real-time monitoring of patient's health and can aid in making online scheduling of tasks more competent. These artificially intelligent devices have proven to have real-time decision-making capability and can lead patients to take immediate action during any adverse health condition[12]. Recently, many studies have been conducted on how to submerge data from different fields of genomics, sensory data, and clinical data with wearable fitness (IoT) devices. The collection of heterogeneous health-related data and integration of a real-time life-logging system can do wonders in the field of healthcare. This platform seems to have a flexible architectural system and can data exchange among different servers easily[17].

Advances in miniature-style wearable devices, along with the collaboration of electrochemical biosensors, logarithms of artificial intelligence, and microfluidics have led to the real-time sensing of body vitals. Modern devices can even configure the data from epidermal, dental interfaces, and ocular surfaces to gather the electrophysiological signs and interpret real-time health conditions[18]. Moreover, tear-based technology has also been put forward which can analyze the concentration of analytes in blood, as tears are bio-fluid having directly released molecules from blood, therefore can correlate to analytes concentrations more accurately. These technologies have been put to work successfully for the determination of glucose levels in the body of the patient and can lead to real-time assessment[19].

The Internet of Things (IoT) is a new concept that allows the collaboration of smart devices to sense the changes in environment in the real time. Recently, researchers have provided an effective e-health system based on 4 layers involving layers of sensors, services, internet, and network as well. These layers can work collectively in a planned framework to give clinical laboratories an ease of data interpretation[20]. In 2020, investigators deduced a model for the electronics-integrated dressing for wounds which could provide real-time healing situations of wounds and can help in monitoring the wound at remote locations making it easy for both health care providers and clinical laboratories. Also, the patient's hustle to do monitoring visits could be reduced easily[21].

Therapy providers in the healthcare sector can deal with patients more swiftly by using the concept of the Internet of Things (IoT). Particularly, elderly people are more susceptible to conditions like insomnia. By using specified heart and sleep rate trackers, more effective therapy sessions can be made possible, providing ease at both the patient's and therapist's end[22]. Moreover, the recently developed wearables can act as a lab under the skin by providing clinical data based on the interstitial fluid of the wearer's body.

These devices use microneedling and prickling to collect real-time data on the patient's health and can reduce lab requirements[23]. Other than that, real-time infection-detecting Internet of Things (IoT) devices are also being introduced to help with the detection of infectious diseases and their treatment strategies. This technology helps in reducing lab contamination and can easily provide on-site and point-of-care analysis. In this way, spreading infectious diseases to lab workers can also be reduced[9].

In Iran, cloud laboratory services are being processed to experience lab testing by receiving data through IoT technologies [24]. This method is based on receiving patient's data online through their cloud medical system and, in turn, the providence of the lab testing results. This helps remotely transmit analyzed medical data from patients to lab workers and vice versa[11]. Researchers have shown the use of Internet-of-Things (IoT)-enabled autonomous integrity monitoring mechanisms for maintaining medical healthcare devices for securing patient data coming from sensors and storing it in a particular manner to deduce an appropriate real-time outcome[25, 26].

The latest studies have suggested using the Internet of Medical Things (IoMT) to deal with diabetic patients and provide remote insight into the patient's health status. These methods have been found appropriate to deal with the patient's diabetic status by using diabetic sensors, cloud-storage systems, and the Internet for online processing[27]. Some studies have even released some of the limitations of IoT systems, as they can have issues while dealing with the integrity of records and their management. Also, the cost and consumption of energy can be a bit more for the initial strategies but can provide success in the long run[10].

Researchers have even proposed the usage of a healthcare and digital twin combination to maintain healthcare services for elderly people. This can have a positive effect on the availability of services for elderly people and can result in more accurate and faster services[28]. Also, integrated cloud computing and IoT can provide a revolutionary change to the health care units in these modern times so that caregivers can remotely interpret data through a pervasive patient health monitoring system (PPHMS) [29].

In the clinical centres for cardiac rehabilitation, IoT can help provide a telerehabilitation platform for integrating cardiac patients of elderly age[30]. A cervical cancer detection model of IoT has been proposed to regulate the real-time monitoring of patients with such disease conditions. This model also included visual-based information for more in-depth knowledge of the disease[31, 32].

Methods

The research determines that Integrating IoT devices in Clinical Laboratories for Real-time Monitoring. This research is based on primary data analysis to determine the research and develop different questions related to the indicators these questions fulfil from participants. For measuring, the research used SPSS software and generated results, including correlation coefficient, chi-square analysis, and regression analysis between them.

Features

Clinical laboratories' efficiency, accuracy, and real-time monitoring capabilities may be significantly enhanced by integrating IoT (Internet of Things) devices. Processes may be streamlined, data accuracy can be improved, and insightful information can be obtained for improved decision-making. The following are important actions and things to think about while putting IoT into clinical laboratories:

1. Determine the Important IoT Integration Domains:

Ascertain which laboratory processes stand to gain from real-time observation. This might involve monitoring inventory, monitoring temperature, and more.

2. Pick Appropriate IoT Devices:

Pick IoT devices that work with the tools and procedures used in laboratories. Sensors for pressure, temperature, and humidity, as well as RFID tags for inventory management, are common equipment.

3. Connectivity and Communication Protocols:

Verify that the chosen Internet of Things devices connect to the lab network using the proper communication protocols. For data transfer, common protocols include MQTT, CoAP, or HTTP/HTTPS.

4. Data Security and Privacy:

Adopt strong security measures to safeguard private patient information and abide by privacy laws. Use access controls, secure authentication, and encryption to protect the transferred data.

5. Integration with Laboratory Information Management Systems (LIMS):

To ensure a smooth information flow, integrate IoT data with Laboratory Information Management Systems, which is currently in place. This combination may improve capabilities for reporting and data analysis.

6. Real-time Monitoring Dashboard:

Create an intuitive dashboard for monitoring in real-time. This can provide laboratory workers immediate visibility into crucial metrics to respond quickly to abnormalities.

7. Remote Monitoring and Alerts:

Turn on the features that enable laboratory workers to view data and get alerts on their computers or mobile devices through remote monitoring. This reduces downtime and guarantees prompt resolution of problems.

8. Power Management:

Consider power management options for Internet of Things (IoT) devices, particularly when the devices are placed in hard-to-reach places. It could be better to use energy-efficient or battery-powered gadgets.

9. Scalability:

Build the IoT infrastructure with scalability in mind to enable future modifications or additions to the laboratory layout.

10. Compliance with laws:

Verify that the deployment of the Internet of Things conforms with healthcare standards and laws, including the Food and Drug Administration's recommendations and the HIPAA Act.

11. Training and Change Management:

Train lab personnel on using and analyzing data from Internet of Things devices. To make the switch to the new monitoring system easier, implement change management techniques.

12. Continuous Improvement:

Regularly evaluate the IoT system's performance and obtain input from the laboratory personnel. Utilise this knowledge to optimise the system for increased efficiency and ongoing improvements. IoT integration in clinical laboratories may be carefully planned and implemented to increase data accuracy, operational efficiency, and real-time monitoring for better patient care results.

Correlations

Table 1

		Integrating IoT Devices 1	Integrating IoT Devices 2	Integrating IoT Devices 3	Clinical Laboratories 1	Clinical Laboratories 2	Real-time Monitoring. 1	Real-time Monitoring. 2	Real-time Monitoring. 3
Integrating IoT Devices 1	Pearson Correlation	1	-.307*	.179	.049	-.008	.203	.023	-.252
	Sig. (2-tailed)		.030	.213	.734	.957	.158	.875	.077
	N	50	50	50	50	50	50	50	50
Integrating IoT Devices 2	Pearson Correlation	-.307*	1	-.360*	.356*	.082	.053	-.319*	.221
	Sig. (2-tailed)	.030		.010	.011	.570	.713	.024	.122
	N	50	50	50	50	50	50	50	50
Integrating IoT Devices 3	Pearson Correlation	.179	-.360*	1	-.344*	.110	-.508**	.615**	-.044
	Sig. (2-tailed)	.213	.010		.014	.445	.000	.000	.759
	N	50	50	50	50	50	50	50	50
Clinical Laboratories 1	Pearson Correlation	.049	.356*	-.344*	1	-.146	.210	-.267	-.076
	Sig. (2-tailed)	.734	.011	.014		.311	.143	.061	.598
	N	50	50	50	50	50	50	50	50
Clinical Laboratories 2	Pearson Correlation	-.008	.082	.110	-.146	1	-.083	.188	.376**
	Sig. (2-tailed)	.957	.570	.445	.311		.565	.191	.007
	N	50	50	50	50	50	50	50	50
Real-time Monitoring. 1	Pearson Correlation	.203	.053	-.508**	.210	-.083	1	-.356*	-.147
	Sig. (2-tailed)	.158	.713	.000	.143	.565		.011	.308
	N	50	50	50	50	50	50	50	50
Real-time Monitoring. 2	Pearson Correlation	.023	-.319*	.615**	-.267	.188	-.356*	1	.043
	Sig. (2-tailed)	.875	.024	.000	.061	.191	.011		.769
	N	50	50	50	50	50	50	50	50
Real-time Monitoring. 3	Pearson Correlation	-.252	.221	-.044	-.076	.376**	-.147	.043	1
	Sig. (2-tailed)	.077	.122	.759	.598	.007	.308	.769	
	N	50	50	50	50	50	50	50	50

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

The above result describes that correlation coefficient analysis between dependent and independent variables presents some negative and positive interrelation. the result presents the Pearson correlation, significant values and number of observations of each mediator variable, dependent variable and independent variable. The rates are -0.252, 0.221, -0.044, and -0.076, respectively, showing positive and negative.

IoT Devices Leading Towards Advancement

IoT accounts for the Internet of Things, physical devices with different types of sensors, related software, and other advanced technologies that allow them to connect with the Internet and transfer data among other software and objects. Such devices gather, add up, and transfer data using sensors and, therefore, offer many applications among various industries, i.e., healthcare and environmental sectors. Among healthcare centres, these devices propose benefits such as wearable health devices, equipment for smart labs, and medical devices for connections.

Integration of IoT Devices in Clinical Laboratories

Common types of IoT devices used in clinical and healthcare labs range from simple to advanced categories. For instance, Radio-Frequency Identification (RFID) tags are used to identify items and components in a sample. Sensors specialized for environment monitoring help in sensing humidity, temperature, and air quality in labs, allowing efficient storage conditions for samples and instruments. Wearable health devices like smartwatches and fitness trackers provide remote analysis of health data. Similarly, IoT-based smart lab equipment is present that can predict its maintenance and performance. Moreover, medical devices that remotely monitor patients' glucose levels have been introduced. Smart thermometers are present that can sense changes in optimum laboratory conditions and respond automatically to required adjustments. Telehealth services are being given to patients remotely by combining IoT and medical devices so that the information can be transmitted between patients and caregivers so that they can give teleconsultation. The detection of falls in elderly or medically impaired people is also an achievement of the IoT system, which provides smart wearable devices to track any haphazard falls or emergencies and can send signals to caregivers and lab managers.

Regression analysis

Coefficients

Table 2

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.213	.575		.370	.713
	Integrating IoT Devices 1	.100	.160	.097	.624	.536
	Integrating IoT Devices 2	.078	.118	.105	.665	.509
	Integrating IoT Devices 3	.053	.197	.055	.269	.790
	Real-time Monitoring. 1	.039	.166	.040	.236	.815
	Real-time Monitoring. 2	.180	.175	.184	1.028	.310
	Real-time Monitoring. 3	.340	.131	.378	2.595	.013

a. Dependent Variable: Clinical Laboratories 2

The above results represent that regression analysis results describe that unstandardized coefficient values included beta and standard error, which also describe the standardized coefficient value of the independent model between the dependent variable. The result describes that the t statistic and significant values of each independent variable in the integrating IOT devices 1,2 and 3 show that beta values are 0.100, 0.078 and 0.053. It shows that 100%, 7%, and 5% beta rates the t statistic values 0.624, 0.665, and 0.269, respectively. It shows 62%, 66% and 26% positive links with clinical laboratories. According to the result, probability values are 53%, 50%, and 79%, significantly level between them. Real-time monitoring 1,2, and 3 are considered mediator variables. According to the result, its beta values are 0.040, 0.184, and 0.378, and the t-statistic values are 0.236, 1.028 and 2.595, showing a positive relation between them; the significant values are 81%, 31% and 13% significant levels with clinical laboratories.

Applications of IoT Devices for Real-time Monitoring in Labs

The introduction of IoT devices in clinical laboratories increases the ease of monitoring, management, and efficiency of the laboratory. Following are some applications related to the involvement of IoT in the real-time assessment of lab procedures.

Tracking of Samples and Related Inventories

The supplies provided in a laboratory need to be managed in real-time to track the requirement of new stock and to get rid of the expired ones. For this, IoT-integrated inventory systems that keep records of stock collection and its manufacturing and expiration dates have been put forward. These systems can also place new orders when a certain usage limit is reached.

Record of Logging into Costly Equipment

IoT has made it possible for researchers in the laboratory to manage the equipment in real-time while being at distant locations. To enable this, IoT-based systems are connected to cameras and equipment setup to access the experimental situation from any location. These types of trackers and sensors allow the researchers to monitor instruments but also make the instruments efficient enough to develop real-time reports based on processes and equipment functioning and can work well in quality control labs. Also, the information on logging into the data and records can be saved and retrieved whenever required, making the system efficient and conserved.

Management of Information Related to Supply Chain and Quality

The association of laboratory-related data with seamless IoT data helps comprehensively in the management of clinical laboratories. With this system, the data gathered from IoT functioning can be directly connected to the LIMS platform and let the user analyze, store, or retrieve data. For the secure deliveries of material, reagents, or samples in the laboratories, IoT devices can help by providing insight and visibility to the whole supply chain, ensuring the timely arrival or departure of material in and out of the laboratory. This feature also reduces the workload of the staff. For making sure of the condition that a working laboratory meets its quality standards, IoT sensors have been generated that can sense the changes in quality parameters like pH, real-time feedback, and conductivity of the samples. Such sensors allow the notification of alerts in case of any quality alteration act.

Monitoring of Environmental and Laboratorial Factors

Environment-related IoT-based sensors can provide alerts in storage spaces if the conditions diverge from the required levels. This response helps maintain the integrity of the samples and can increase their shelf life. For the optimal performance of the instruments present in the laboratory, IoT plays a noteworthy role. Such types of IoT sensors can track usage patterns, offer real-time preventive measures, and help troubleshoot faults, errors and anomaly detection.

Sensors for Privacy Management

Smart devices have been made that, upon linkage with the IoT concept, provide beneficial tracking of activities in elderly and disabled people. These trackers connect the health information directly to lab management and can make them aware of any emergencies. To keep authorized data private, different types of IoT trackers have been introduced that can easily manage the security of the systems and only allow specific people to access data and make required amendments.

Energy Conservation

This IoT mechanism allows the laboratory management to have a real-time lead on the laboratory's energy consumption rate. This reduces the economic load on the labs and working departments, which in turn helps to focus on enhancing the workflow of the clinical labs for better outcome services. To aid this cause, smart lighting systems are connected to IoT devices that are efficient enough to adjust energy utilization depending on laboratory requirements and tenancy. Despite having these significant and crucial advantages in clinical laboratories, IoT systems are still under debate under certain conditions in which data privacy needs to be prioritized. Furthermore, training and proper schooling of staff and workers encountering the laboratory premises must be done properly so that the operative and sustainable environment can be provided to the IoT-integrated clinical laboratories and the efficacy and competence of such networks is made possible in the long run of advanced medical opportunities.

ANOVA[a]

Table 3

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.474	6	.412	1.650	.157[b]
	Residual	10.746	43	.250		
	Total	13.220	49			

a. Dependent Variable: Clinical Laboratories 2

b. Predictors: (Constant), Real-time Monitoring. 3, Real-time Monitoring. 2, Integrating IoT devices 1, Real-time Monitoring. 1, Integrating IoT devices 2, Integrating IoT devices 3

The above result describes the sum of square values, mean square, and F statistic. Also, the significant value of each model included regression, residual and total. The sum of square values of regression is 2.474, the residual value is 10.746, and the total value is 13.220, respectively.

The mean square value of regression and residual values are 0.412 and 0.250, which shows 41% and 25% average square values, respectively. According to the result, the F value is 1.650, and its significant value is 0.157, showing a positive and 15% significant value between them.

Test Statistics

Table 4

	Integrating IoT Devices 1	Integrating IoT Devices 2	Integrating IoT Devices 3	Clinical Laboratories 1	Clinical Laboratories 2	Real-time Monitoring. 1	Real-time Monitoring. 2	Real-time Monitoring. 3
Chi-Square	37.960[a]	11.320[a]	24.520[a]	25.240[a]	32.920[a]	25.720[a]	28.840[a]	23.680[a]
df	2	2	2	2	2	2	2	2
Asymp. Sig.	.000	.003	.000	.000	.000	.000	.000	.000

a. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 16.7.

The above result describes that test statistical analysis results represent the chi-square values and the probability value of each variable, including independent and dependent variables. The chi-square values of integrating IOT devices 1,2 and 3 are 37.960, 11.320 and 24.520. These values show the positive chi-square rates of independent variables. Clinical laboratories 1,2 are mediator variables. According to the result, their chi-square values are 25.240 and 32.920; both present positive chi-square rates. The real-time monitoring 2,3 describes that chi-square values are 28.840 and 23.680, respectively. The overall significant value is 0.000, which shows a 100% significant level between the dependent and independent variables.

Conclusion

To sum up, integrating IoT devices for real-time monitoring in clinical laboratories offers a transformational opportunity to improve overall laboratory administration, accuracy, and efficiency. Labs may transform their operations and guarantee top-notch patient care by using IoT technology. Considerations including data security, smooth connection with current systems, and compliance with healthcare legislation should direct the deployment process. Real-time monitoring of vital indicators, remote access and management of laboratory data, and quick reaction to anomalies are all advantages of IoT integration. Enhancing operational workflows and guaranteeing the dependability of diagnostic and testing procedures also helps improve patient outcomes—the research is based on Integrating IoT devices in Clinical Laboratories for Real-time Monitoring.

The study used SPSS software to measure and generate results, including correlation coefficient, regression analysis, and chi-square analysis. However, ongoing training for laboratory personnel, thorough planning, and consideration of security and privacy safeguards are necessary for a successful deployment. The system must be designed with scalability and adaptability in mind to allow for future technological developments and modifications in laboratory requirements.

Continuous improvement should be a significant priority as labs enter the IoT age. Regular evaluations and feedback loops will drive adjustments to maximise system performance. Overall, the research concluded a significant link between Integrating IoT devices in Clinical Laboratories for Real-time Monitoring. Ultimately, there is a lot of potential for improving healthcare delivery, research, and diagnostic capacities by integrating IoT devices into clinical laboratories. It opens the door to a more responsive and integrated healthcare environment, encouraging efficiency and innovation in patient care and diagnosis.

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