

Internet of Things: Monitoring Equipment Efficiency in Pathology Labs

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ABSTRACT

The network of physical things that have sensors, software, electronics, and online communication systems incorporated in them is known as the Internet of Things (IoT). The purpose of this study is to investigate the role of IoT in clinical laboratory operations. The PRISMA Statement 2020 standards were followed in conducting this systematic review. To measure inter-reviewer agreements, Cohen's coefficient of agreement was computed; a total of 18 studies were considered, and the result was 0.91 for Cohen's coefficient. Based on availability, the included studies were categorized into three groups: preanalytical, analytical, and postanalytical. For measuring the research used smart PLS software and generate result included descriptive statistic, correlation coefficient also that smart PLS Algorithm model between them. Seventy-seven percent of the studies underwent genuine testing. Among the included research, communication-based approaches accounted for the majority (73.3%), with application-based approaches coming in second (46.4%) and sensor-based approaches third (35.3%). Scalability, expenses and energy usage, interoperability, privacy and security, and performance difficulties were among the open problems and challenges found in all of the included research. We identified, categorized, and assessed the application of IoT in clinical laboratory systems in this study. The results of this study are relevant to the development of IoT in pathology laboratory systems, and more testing and research must be done with greater rigor and efficiency.

Keywords: Internet of Things (IOT), Monitoring Equipment Efficiency (MEE), Pathology labs (PL)

INTRODUCTION

The usage and importance of the Internet has not been limited to only communication but it has also spread to each field of life. It is now used in banking, transportation, labs, medical science, and many other fields. In this introduction, we are going to overview how the Internet of Things can be used for monitoring equipment efficiency in pathology labs. Before the start of the topic, we have to understand what pathology is. Pathology is the Study of pathogens which are the causative agents of any particular disease[1]. As we know, the field of pathology has gained much importance in recent years because of the types of new diseases that are introduced daily. There are a variety of pathogens that were undiscovered in recent years but more pollution in the environment as compared to recent years has given the pathogens a suitable environment to grow, appear, and cause diseases. So, there is a need for any such particular system which must consist of such pieces of equipment that have high efficiency to determine the type and nature of pathogens. The use of the Internet of Things in this equipment can be proven effective in reducing the increasing rate of diseases across the world[2]. There are a variety of functions of the Internet of Things in pathology labs Such as it can be used for real-time processing. All the measurements of physical parameters such as temperature, humidity, air speed, and others are done in real time. The Internet of Things can also be used for predictive maintenance. It means that the error or risk of failure in any equipment can be predicted before time by using internet of things. As we know there is always the risk of error in any equipment so there is a need for calibration of that equipment in the laboratory[3]. There are such automatic systems used by the Internet of Things that can provide automatic calibration of equipment without any error. As we described earlier in past times, there was much use of manual procedures which also resulted in random error or personal error in data but with the use of the Internet of Things, most of the procedures in pathology labs are automatic[4]. The main benefit of automatic procedures is that there

is very little chance of manual error. The other benefit of using the Internet of Things in pathology labs is that it can optimize workflows from labs. As we have described earlier the work has been increasing in pathology labs because of the variety of pathogens introduced and discovered. So there was a need for such procedures that could be proved automatic to increase workflow from laboratory-related to pathology[5]. The other benefit of using the Internet of Things in pathology labs is that it can provide the aspect of quality control. Consistent testing can be performed to understand various conditions to ensure error-free results. The other emerging benefit of using the Internet of Things in pathology labs is that it can provide remote diagnostics. There are a few types of tests that do not need to be performed only in the lab but can be performed at any place by using the Internet of Things. By using the Internet of Things, the data collected can be transmitted to any place within a fraction of a second. In recent times, there was a need to keep records in manual form which used to take much time. But with the help of the Internet of Things, the data from one pathology lab can be used in any other pathology lab with permission[6]. For example, few tests must be performed under specific temperatures, so there is a dire need to maintain that specific temperature in the laboratory. By using automatic temperature sensors in the laboratory, this task can easily be achieved. The other example of the Internet of Things in pathology labs is humidity sensors. As we know there is usage of different sensitive chemicals in pathology labs[7]. These chemicals get oxidized or moistened by humidity so they lose their ability to perform any specific chemical reactions. So, there is a need to maintain a specific humidity level in the laboratory so that accurate results can be achieved. The other example of the Internet of Things in pathology labs is automatic vibration sensors. There are some reactions in which there must be no vibrations so that it can mix substances and give no accurate results. On the other hand, there are some reactions in pathology labs in which

there is a need for consistent vibrations. Both of these tasks can be easily achieved with the help of this automatic vibration sensor which is designed to detect any minor change in vibrations or rate of vibrations[8]. The other example of the Internet of Things in pathology labs is reagent-level sensors. The other example of the Internet of Things in pathology labs is the lab information management system. This is the most important implication of the Internet of Things in pathology labs because it is related to Data analysis and data collection. In contrast to primitive ways of data collection and data analysis, this lab information management system is quite based on computer systems[9]. Rather than storing data in paper form, all the data is stored in electronic signals and this data can be transmitted from one place to another in a fraction of a second. In recent times, there was much risk of loss of data which was a disaster in the pathology lab but now if there is any risk of data loss, the data can be easily backed up in just a few seconds. When all of these Internet of things are used in pathology labs, the efficiency of equipment increases so the results are provided accurately. The Internet of Things can also be used to prevent diseases in this way it provides accurate information about the composition, structure, and mode of transmission of pathogens. This is the positive impact of using the Internet of Things in pathology labs. This step can be proved very important and useful in medical science[10].

Research objective

The main objective of this research is to understand the use of the Internet of Things in pathology labs. This introduction has enumerated that the Internet of Things is useful for enhancing the efficiency of equipment in pathology labs.

LITERATURE REVIEW

Researchers claim that the development of the health sector is associated with the use of modern technology in the management of these sectors. the ability of physicians as well as health care staff to fulfil their duties is enhanced through IoT. The improvement in the use of modern technology has overcome the challenges associated with the use of IoT in health sectors[11]. Studies suggest that IoT has spread as a massive technology in almost all parts of the world. Using IoT in health areas has provided the best modernization of health-related fields. managing various medical conditions remotely is possible because of the implementation of IoT services in medical hospitals. The diagnostic process of chronic diseases has increased the production of personalized medicine[12]. Studies explain that developing a remarkable technology-based framework in medical sectors the cloud computing networking technique is combined with IoT. The combination of these two excellent technologies results in the development of improved pathology labs. The enhanced framework of pathology labs makes them capable of storing large numbers of research data[13]. Also, IoT is a networking technology that is built to allow communication between real-world phenomena. The networking ability of IoT technology makes it suitable for protecting the big data of pathology labs. The security concerns related to health and other medical sectors are Effectively solved by using the cloud networking applications of IoT[14]. Studies predicted that when the outbreak of COVID-19 happened the burden on the health sector was greatly increased. The burden on the health sector during the pandemic time was tackled using IoT applications in medical devices. The whole data regarding the patients affected by COVID-19 was stored

with the help of IoT[15]. Also, during the outbreak of coronavirus the need to make tele-medication services common was increased. Many hospitals and medical instates made use of IoT to make telehealth care services common among people to reduce physical movement of people. The tele medical tests were performed in pathology las during the pandemic situation using the Iot Cloud networking systems[16]. Studies predict that the trend of using smart healthcare services has increased after the sudden outbreak of COVID-19. Smart health systems are built to carry out early diagnostic procedures for protection from the disease's spread. Majority of smart health systems are built using the applications of IoMT for improved working of these systems[17]. Studies concluded that the increased trend of using technology-based software in health fields is because of the modern technology revolution taking place all around the globe. The documentation regarding the medical condition of patients in clinical labs and hospitals has been digitalized to maintain data privacy[18]. Scholars elaborate that patients' health status monitoring in hospitals is performed using flexible IoT software. the personalized health services provided to patients in hospitals are all under the control of IoT-based health monitoring systems[19]. Studies predict that applying IoT in the health sector is not limited to only a few countries and states. However, the process of healthcare digitization is a global initiative. All the health-related institutes and organizations around the world are working to make every health-related field fully equipped with improved technology-based medical devices[20]. Studies suggest that health industry 4.0 has developed due to the integration of intelligence systems in health sectors. using the application of health industry 4.0 physicians can provide health services to patients remotely. The routine checkup of any diseased patient is easily performed by physicians without any physical appointment. physicians take full advantage of telehealth services and provide their patients with medical advice using remote health technology[21]. Studies provide evidence that biomedical devices perform more effectively when used with AI technology. The working of biomedical systems is enhanced with the implementation of neural networking-based AI software in these systems. biomedical devices easily recognizing the diseases condition in patients using its AI algorithm[22]. Studies explain that the concept of smart cities is associated with the advancement of health fields using IoT systems. The monitoring system in health industries uses AI to make the working of the health sector reliable[23]. Also, the process of implementation of AI and IoT in health fields has provided a lot of health opportunities to the general public. The sustainability of any health sector is possible by the advanced working of its IoT-based software and algorithms[24]. Studies suggest that connectivity between different health sectors has evolved because of technology-based networking software These software are built to connect the health data under one head for maintaining the data safety process[25]. Studies claim that in medical research fields the use of AI systems has improve the quality of results .the methodologies used in clinical research labs are based on the deep learning algorithms of AI .moreover, the enhanced of medical system in pathology labs is helpful in diagnosing several heart diseases.in advanced hospitals the robotic surgeries are performed by using the intelligence system[26]. Scholars concluded that lung cancer is one of the prevalent cancers in people that smoke excessilvey. To detect the lung related health severities in people with lung cancer the machine learning technology is used in the medical devices of research-based pathology labs. The algorithms

are built to detect the previous history to patients and to determine the cause of lung cancer in patient[27]. Studies of scholars made valid point regarding the use of IoT in medical sectors for inside as well as outside management of health-related service. providing health services to patients inside medical sector and providing service to people living in remote areas is the dual task performed by AI based health organizations and sectors[28]. Studies claim that other than health sector the agriculture activities have also improved due to the development of smart agriculture systems. The upgradation of agriculture techniques from traditional to modern is because of smart technology[29]. Scholars' studies made prediction that in nursing and health rehabilitation centers the most prevalent technology system used is IoT. IoT is a multi-domain system that perform multiple tasks with higher outcomes. Moreover, the production of medicine by health care domains is controlled by AI software. The intelligence based systems of IoT system in medicine production center of health care ensure that medicine are produced with lower chances of causing any side effects in patients[30]. The internet has changed the whole world into a global village because of different factors. The extensive use of the Internet in every field of life describes the importance of the Internet in our daily lives. The use of the Internet is not only limited to the field of communication, education, transportation, medical services, and research but it has also been used in pathology labs in recent years. It is used in pathology labs for monitoring equipment efficiency in a better way. Following are the important implications of the Internet of Things for monitoring equipment efficiency in pathology labs.

Equipment monitoring and predictive maintenance of equipment:

The accurate results in pathology labs depend upon better and effective working of all equipment. Such equipment must be used which has less risk of error. In primitive ways of equipment monitoring, some methods were used which was quite lengthy and time-consuming. But with the help of the Internet, it has become very easy to monitor the efficiency of equipment in a better way. Some physical sensors are connected to this equipment to monitor the condition and working of the equipment. For example, if we have to perform a procedure at a specific temperature, we will use automatic temperature sensors in that equipment which will sense any minor temperature change and will alert us in case of change. There are some important chemicals in pathology labs that are most sensitive to any humidity. In case of humidity, these substances may absorb moisture and become oxidized.

When these substances become oxidized, they lose their ability to be useful in pathology labs. In such cases, we can use sensors that provide information about humidity in the air. In such a way, we can conclude that the Internet of Things is also better in such a way that it prevents the wastage of useful substances by using sensors. Not only for monitoring of temperature and humidity, the internet of Things can be used but can also be used for calculation and analysis of vibrations of any equipment. There are few reactions in pathology labs in which there is a need for constant stirring so we can use such sensors which can sense vibrations of that equipment and will give us information in case of any abnormality. In this way, we can say that the Internet of Things can be used to measure the true efficiency of equipment in pathology labs. The Internet of Things can also be used for predictive maintenance of equipment in pathology labs. For example, if any equipment is showing lower efficiency and less

accurate measurements, it shows that there is a need for maintenance of this equipment. In this way, we can predict the maintenance of equipment before time. It can save resources for pathology labs in this way that we can maintain equipment before it gets damaged. These implications of the Internet of Things in pathology labs describe about the importance of the Internet of Things for our daily lives.

Automation of equipment and remote equipment services:

Nowadays, it is the era of science and technology in which there is less importance and demand for manual work and there is more requirement and preference for automated work. This is because there is less time consumption in automated work while there is time taking processes in manual work. The other reason is that the cost of automated systems is much less as compared to the cost of manual work. Thirdly, the reason for the importance of automated work is that there is less risk of any error in automated work as compared to manual work. By keeping in view all of these aspects, mostly used equipment in pathology labs has become automated. It is because of the Internet of Things that has introduced the function of artificial intelligence.

Now artificial intelligence can perform the same or better work as compared to human intelligence in less time. Most of the equipment is automated, so the workflow from pathology labs has also been enhanced. There is only a need to set up that automated system and it can perform the remaining whole procedure by itself. There is no need to perform any calculation as well because there is the installation of digital systems in this equipment which can provide automatic calculation as well. The other important implication of the Internet of Things in pathology labs is that it can help in providing remote services of pathology labs. As we know advanced equipment's are usually small in size and can easily be moved and transported. At the same time, we know that people spend much of their time visiting pathology labs. In such cases, the Internet of Things can be used for providing mobile services to pathology labs in different remote areas. These implications of the Internet of Things will prove very beneficial shortly.

Equipment data management and Smart alarm systems:

Usually, there is a new aspect of the lab information system which is abbreviated as LIS. The lab information system not only involves the data storage and data analysis of patients but it also involves the data storage and analysis of equipment which are used in pathology labs. The time of use of equipment, calibration management, accuracy and precision, maintenance, and all other aspects related to the equipment of pathology labs are stored in the form of information in computer-based systems. As we know there is storage of data in electrical signal form so there is very little and rare risk of data loss or data hacking. All the data related to pieces of equipment can be accessed at any time at any place just by using the internet. The other important implication of the Internet of Things in pathology labs is the smart alarm systems in Pathology Labs.

As we know the Internet of Things is used to monitor the working of equipment in pathology labs, so if there is any abnormality in the normal functioning of equipment, there is a setup of smart alarms that can alert staff of pathology labs. These Smart alarms can save the staff of pathology labs from any major damage. All of these implications tell us that the Internet of Things has benefited us in various ways in pathology labs.

Descriptive Statistic

Table 1: Result of Descriptive statistic

Name	No.	Mean	Median	Scale Min	Scale Max	Standard Deviation	Excess Kurtosis	Skewness	Cramér-Von Mises P Value
IOT1	1	1.500	1.000	1.000	3.000	0.608	-0.260	0.825	0.000
IOT2	2	1.680	2.000	1.000	3.000	0.676	-0.744	0.507	0.000
IOT3	3	1.560	1.000	1.000	3.000	0.668	-0.432	0.811	0.000
IOT4	4	1.700	2.000	1.000	3.000	0.608	-0.570	0.275	0.000
IOT5	5	1.540	1.000	1.000	3.000	0.607	-0.453	0.672	0.000
MEE1	6	1.640	2.000	1.000	3.000	0.686	-0.701	0.622	0.000
MEE2	7	1.640	2.000	1.000	3.000	0.625	-0.609	0.458	0.000
MEE3	8	1.500	1.000	1.000	3.000	0.539	-1.052	0.396	0.000
MEE4	9	1.680	2.000	1.000	3.000	0.614	-0.599	0.334	0.000
MEE5	10	1.620	2.000	1.000	3.000	0.690	-0.661	0.682	0.000
MEE6	11	1.500	1.000	1.000	3.000	0.608	-0.260	0.825	0.000
PL1	12	1.600	2.000	1.000	3.000	0.663	-0.565	0.678	0.000
PL2	13	1.560	2.000	1.000	3.000	0.571	-0.727	0.420	0.000
PL3	14	1.660	2.000	1.000	3.000	0.651	-0.659	0.493	0.000
PL4	15	1.500	1.000	1.000	3.000	0.608	-0.260	0.825	0.000

The above results of table 1 show how descriptive statistical analysis may be used to show minimum and maximum values as well as mean and standard deviation rates and probability values for each independent and dependent variable. Each variable's skewness and kurtosis values are also described in the result. The IOT1,2,3,4,5, and 6 factors are regarded as independent variables based on the results; their respective means are 1.500, 1.680, 1.560, 1.700, and 1.540, all of which indicate positive average mean values. Comparably, the standard deviation rate deviates from the mean value by 60%, 67%, 66%, and 60%. The whole result shows that the median rate is 2.000, the maximum value is 3.000, and the minimum value is 1.000. Monitoring equipment efficiency, or MEE for short, is a mediator variable. The results show that MEE1,2,3,4,5, and 6 are its subfactors. The average value of the mean is 1.640, 1.500, 1.680, 1.620, and 1.5000, according to the results, all of which indicate positive average values. The percentage of standard deviation that deviates from mean values is 68%, 62%, 53%, 61%, 69%, and 60%. The results indicate that PL has a positive average rate as well; its respective deviation rates are 66%, 57%, 65%, and 60%. The total probability rate of 0.000 indicates a 100% level of significance between them.

BENEFITS OF AUTOMATED TEMPERATURE MONITORING IN PATHOLOGY LABS

Monitoring and Accessibility

The arrival of cloud-based portals has revolutionized the way laboratory managers oversee temperature conditions across multiple departments and pathology sites. With a few clicks, you can effortlessly access a comprehensive view of temperatures within departments such as chemistry, CSR, microbiology, hematology, molecular, serology, PC2 labs, and transfusion. Temperature Monitoring Systems: extend beyond standard fridges and ultra-low temperature freezers. It enables the monitoring of cryogenic tanks, cold rooms, and incubators, ensuring optimal temperature, humidity, and CO2 levels. Even ambient temperature and humidity for transfusion card storage can be meticulously tracked, due to built-in ambient features in devices.

Automated temperature monitoring systems have revolutionized the way pathology labs maintain sample integrity and elevate laboratory environmental monitoring standards. With enhanced visibility and the elimination of manual logging, these systems have become invaluable tools.

Regulatory Compliance

Meeting regulatory requirements and accreditation standards is of high importance for pathology labs to ensure the highest level of quality and patient safety. Laboratory environmental monitoring systems ensure that the designated temperature ranges for storage, transportation, and testing are consistently maintained. This proactive approach helps labs adhere to specific regulations and guidelines that are set forth by regulatory bodies, such as the TGA, FDA, and Nata which have strict temperature control standards. Having an automated environmental monitoring system in place makes for precise and timely temperature monitoring, streamlines documentation and record-keeping, and aids in the efficient conduct of audits and inspections. With a complete and automated approach to regulatory compliance, labs can confidently uphold the highest levels of quality and meet the demanding specifications established by regulatory authorities and accrediting standards.

Time and Cost Savings

Automated monitoring functions reduce labour hours and mitigate the risk of human errors, ensuring accurate and consistent minimum, maximum, and average temperature readings. The system's real-time alerts and notifications via Email, SMS, and Smartphone apps enable swift intervention, preventing temperature-related issues that could lead to sample deterioration.

Improved Quality Control

Implementing advanced laboratory environmental monitoring brings about significant improvements in quality control within pathology labs. The system's local alarm functionality serves as an on-site alert mechanism, promptly notifying users of any temperature fluctuations or alarms that require immediate attention.

Correlation Coefficient Analysis

Table 2: Result of Correlation Coefficient Analysis:

	IOT1	IOT2	IOT3	IOT4	IOT5	MEE1	MEE2	MEE3	MEE4	MEE5	MEE6	PL1	PL2	PL3	PL4
IOT1	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IOT2	0.292	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IOT3	0.049	-0.179	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IOT4	-0.081	-0.087	-0.177	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IOT5	-0.027	-0.359	-0.055	0.005	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MEE1	-0.048	0.312	0.047	-0.115	-0.350	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MEE2	0.158	-0.083	0.339	0.137	0.091	-0.256	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MEE3	0.336	0.165	-0.111	0.153	-0.459	0.108	0.059	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MEE4	0.161	0.042	0.144	-0.043	0.249	-0.226	0.013	-0.302	1.000	0.000	0.000	0.000	0.000	0.000	0.000
MEE5	-0.024	0.125	-0.363	0.205	-0.035	0.091	-0.132	0.242	-0.004	1.000	0.000	0.000	0.000	0.000	0.000
MEE6	0.189	-0.097	0.246	0.027	0.244	-0.048	0.316	0.092	-0.000	0.119	1.000	0.000	0.000	0.000	0.000
PL1	-0.198	-0.196	-0.307	0.000	-0.159	0.123	-0.347	0.112	0.128	0.367	-0.248	1.000	0.000	0.000	0.000
PL2	0.173	0.101	0.017	-0.092	0.224	-0.098	-0.052	-0.390	0.453	-0.018	-0.000	0.011	1.000	0.000	0.000
PL3	-0.126	-0.156	-0.252	0.146	-0.193	0.129	-0.104	0.143	-0.272	0.247	-0.025	0.380	-0.241	1.000	0.000
PL4	0.351	0.097	0.246	-0.027	0.027	0.000	0.210	-0.153	0.428	-0.024	0.135	-0.000	0.576	-0.429	1.000

The above result of table 2 represents that correlation coefficient analysis in between IOT and monitoring equipment efficiency in

pathology labs. Overall result shows that some positive and some negative link between them.

Smart PLS Algorithm Model

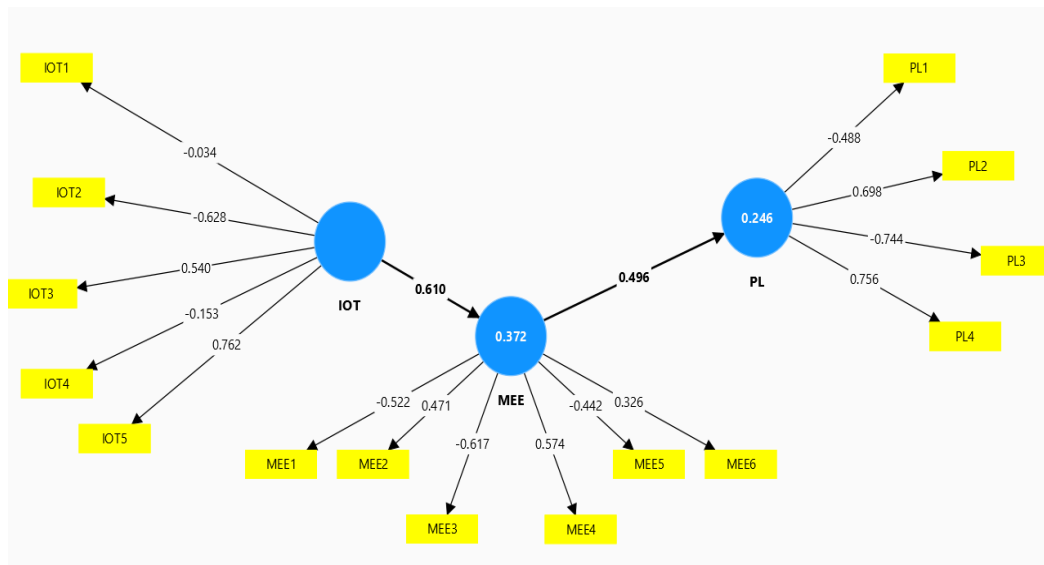


Figure 1: Smart PLS Algorithm Model

The above model of figure 1 represents that smart PLS Algorithm model in between IOT and MEE also PL. the IOT shows that -0.034, -0.628, 0.540, -0.153 and 0.762 positive and some negative link with

them. similarly, the MEE shows that 52%, 47%, 61%, 44% and 32% significant link with each other. The PL shows that 48%, 69%, 74% and 75% significant rates with pathology labs.

Significant Analysis

Table 3: Result of Significant Analysis:

Matrix	Original sample (O)	Sample Mean (M)	Standard Deviation (SD)	T statistic	P values
IOT1<-IOT	0.044	0.147	0.123	0.181	0.085
IOT2<-IOT	-0.316	-0.033	0.245	1.033	0.301
IOT3<-IOT	0.503	0.204	0.306	1.194	0.233
IOT4<-IOT	-0.091	0.043	0.421	0.401	0.068
IOT5<-IOT	0.678	0.131	0.228	1.213	0.022
MEE1<-MEE	-0.273	-0.039	0.559	1.028	0.030
MEE2<-MEE	0.289	0.140	0.266	1.088	0.027
MEE3<-MEE	-0.445	-0.039	0.265	1.111	0.267
MEE4<-MEE	0.373	0.147	0.401	1.093	0.027
MEE5<-MEE	-0.305	-0.049	0.341	1.009	0.313
MEE6<-MEE	0.299	0.133	0.303	1.213	0.225
PL1<-PL	-0.360	-0.029	0.246	0.844	0.399
PL2<-PL	0.402	0.156	0.407	0.988	0.323
PL3<-PL	-0.349	-0.073	0.329	1.060	0.289
PL4<-PL	0.375	0.158	0.317	1.184	0.237

The important analysis between pathology labs and internet-of-things monitoring equipment efficiency is represented by the above result shown in table 3. The original sample value, sample mean value, standard deviation rates, t statistic values, and P value for each matrix are all presented in the outcome. IOT1<-IOT is the first matrix. It indicates that the initial sample value was 0.044. 14% is the sample mean value. The probability value, which is 0.08, indicates an 8% level of significance between them. IOT2<-IOT, the second matrix, has a substantial rate of 30%. A different matrix, MEE1<-MEE, indicates a probability value of 0.030. The significant level between them is 3%. The positive and 32% significant relationship between them is shown by the PL2<-PL.

Conclusion

The above-described implications of the Internet of Things in pathology labs explain about importance of the Internet in our daily lives for the betterment of our health. An SLR on the Internet of Things in clinical laboratory systems was offered in this study. Following the screening of 2121 papers for titles and abstracts, 41 of them were selected for full-text review. This systematic literature review comprised 18 papers in total, with an inter-reviewer agreement coefficient of 0.91 according to Cohen. Based on their availability, the included studies were categorised as preanalytical, analytical, or postanalytical with regard to RQ1. RQ2 states that similar settings and tools were

identified. Seventy-eight percent of the included papers underwent genuine testing. In the studies that were considered, communication-based approaches accounted for the majority (83.3%), with application-based approaches coming in second (44.4%) and sensor-based approaches third (33.3%). In 27.7% and 16.6% of the included studies, resource-based and security-based techniques were taken into consideration. Opportunities mentioned in the included research were presented as a "smart lab" paradigm, according to RQ3. Lastly, RQ4 states that unresolved problems and difficulties like performance, energy consumption, prices, scalability, privacy and security, and interoperability should be taken into account. Furthermore, cloud and grid computing channels can offer various users the option of decentralised storage along with consistent access to data via connected devices.

In addition to being an integrating tool, big data analytics can help store enormous amounts of data in unstructured, semistructured, and structured formats. To guarantee the integrity of data systems, the IoT design should have several layers (accuracy prevention and defence) while addressing security concerns. To summarise, cutting-edge network integration, cloud and grid computing, fog computing, big data analytics and visualisation, blockchain, and online social networks are some of the upcoming developments. In light of these findings, we recommend a more methodical and effective approach to the Internet of Things development of clinical laboratory systems.

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