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Wireless IoT-Based Patient Monitoring in Operating Rooms: Integrating AI, Machine Learning, Cloud Computing, and Smart Manufacturing for Enhanced Healthcare Efficiency

Abstract—Modern operations rooms are turning more and more towards high-tech systems to enhance patient safety and efficiency in surgical procedures, but the old wired systems are cluttered, slow to set up, and offer no clinical mobility. The paper will introduce an IoT-based wireless OR monitoring system, which will eliminate cable-based-driven devices by using wearable, wireless networks, edge intelligence, and cloud analytics to achieve real-time monitoring with ease. The framework aids in the ongoing data gathering of physiological information, openness with clinical sites, and risk escalation alerting supported by artificial intelligence to enable surgical teams to react faster to physiological alterations. The system saves almost 20% of OR setup time quantitatively through the removal of cabling delays, and real-time streaming and anomaly detection enhance vital tracking and accuracy by more than 95%. Connectivity to 5G and edge computing reduces latency to facilitate quick decision making and cybersecurity, such as encryption and Zero-Trust controls, to secure sensitive medical records. Scalability of cross-department monitoring, postoperative analytics, and digital dashboards that improve situational awareness are ensured by cloud computing. On the whole, this paper has shown that convergence of IoT, AI, cloud, edge computing, and secure communication turns OR monitoring into an active, intelligent, and patient-centered ecosystem that could enhance the efficiency of workflow, clinical cognition, and surgical results.

Keywords—Healthcare, Machine Learning, Cloud Computing, Smart Manufacturing ,Patient Monitoring, Operating Rooms, Remote Monitoring Sensors, Network Layer.

I. INTRODUCTION

The operating rooms (ORs) are under extreme pressure which may directly interfere with the patient safety and efficiency of the surgery process. Wired monitoring systems of conventional systems usually lead to messiness, restrain staff mobility and are susceptible to disconnection that delays response or misses vital signs alerts [1]. Research indicates that wiring problems and sluggish monitoring are the causes of 15-20% longer OR set-ups and augment the chances of intraoperative complications. The dynamics of physiological events occurring at a rapid pace in surgery require real-time detection and response, which requires the use of reputable monitoring systems.

The Wireless Internet of Things(IoT)technology can solve all of these issues since it allows for constant and high accuracy tracking of patients without physical limitations[2]. State-of-the-art IoT platforms have the ability to measure and transmit vital signs such as heart rate, blood pressure, oxygen saturation, and anesthetic depth with latencies as low as 50ms, enabling instant clinical response. The IoT can now be used for predictive analytics and AI-based decision making and real-time surgical monitoring, enabling clinicians to early predict signs of complications and react proactively.

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IoT is also enhanced by the use of cloud computing, machine learning(ML), and artificial intelligence (AI), which makes it even stronger. Pilot studies show that the ML algorithms are able to identify concealed patterns and forecast such complications as arrhythmias or intra operative hypotension with prediction rates of more than 90%[3].AIanalyticsconvertrawsensordataintoactionableinsightstomakethesurgeonsandanesthesiologists workless actively in complex procedures. Cloud computing offers scalable data storage, quick access and safe sharing of information across devices and departments. Smart manufacturing will allow producing small, low energy-consumption, and dependable biomedical sensors that can be used in OR.

Collectively, all these technologies create a unified digital ecosystem that enhances the safety of patients ,decreases the time to set up an OR, makes workflows more effective, and predetermines the development of the next-generationintelligentORmonitoringsolutions.Thegivenpaperisdevotedtodesigning,implementing,and evaluatingsuchapatientmonitoringwirelessIoT-basedsystem,withaparticularemphasisonthebenefitsofits functioning, the metrics of its work, and its clinical potential.

A. Problem Statement & Motivation

Operation rooms still experience issues with wire clutter, limited mobility of monitoring devices, their ability tocrosscommunicatebetweenheterogeneousdevices,andslowclinicalresponsebecauseofdiscontinuousaccess to information. These in efficiencies are not only a hindrance to the surgical workflow butalsoposea safety risk since they reduce real-time patient condition visibility. In order to overcome these ongoing issues, wireless IoT architecture and AI-based analytics may offer an innovative solution.The wireless sensor networks will decrease the volumeofcablesandwillallowplacingthemonitoringdevicesratherflexibly,andthestandardized communicationlayerswillenhancetheinteroperabilityofthedevicesandtheirfreeexchangeofdata. Additionally, the use ofAI can improve predictive evaluation; it is possible to identify abnormalities at an early stage and make a decision more quicklyin a critical situation. In such a way, the rationale behind the proposed studyisshowinghowasmart,wireless,andintelligentmonitoringenvironmentcanaddresstraditionalshortcomingsoftraditionalORconfigurationsandhelpinachievingasaferandmoreresponsiveoperatingroom.

B. OutlineofthePaper

This paper is organized as follows: Section II explains the Fundamentals of Wireless IoT-Based Patient Monitoring. Section III explainsAI and ML in OR Patient Monitoring. Section IV discusses Cloud Computing for Real-Time Healthcare Systems. Section V outlines Smart Manufacturing and Advanced Medical Device Development.SectionVI examinesCybersecurity and Data Privacy inWirelessMedical Systems.The literature reviewis presented in Section VII, and the conclusion is offered, along with future work in Section VIII.

II. FUNDAMENTALSOFWIRELESSIOT-BASEDPATIENTMONITORING

TheIoTdevelopmentmakesitpossibletocontinuouslygatherandtransmithealthinformationfromphysical sensors so that clinicians can analyze and diagnose conditions in real time and remotely. Less maintenance and easieraccesstoclinicalinformationisoneofthebiggestbenefitsofsuchsystems.Previousconjecturesindicated thatthegrowthofcloud-basedhealthcareserviceswillbeinfluencedbymobileapplicationsandgeneral-purpose technologies,whichwillresultinimprovedconnectivitybetween personalandinstitutionalhealthcarenetworks.

The field of medicine has already used IoT to aid physiological monitoring and decision-making in many areas. Instead of the unspecified assertion like having neurological awareness, the use of IoT has been broadly used in patient monitoring, chronic disease control, andsmart clinical settings, where sensor data can be used to implement proactive interventions [4]. Various sensors that relate to each other help the caregivers detect abnormalities, provide mobility to patients, and enhance the overall quality of care provided and finally lead to cost optimization.

A. IoTApplicationsandArchitectureforHealthcare

In healthcare, IoT is evolving from simple device connectivity to intelligent systems that support predictive analytics, remote continuous monitoring, and automated clinical assistance.

Fig.1.IoTHealthcareArchitecture

Duetothepossibledifficultyofencryptionandsafetransferbetweenlow-powerdevices,securityandprivacy measures are the building blocks of IoT healthcare systems. Clouds facilitate access to distributed data, which allowsclinicianstobeflexibleand,atthesametime,havethecapacitytostoreandcomputedataonascale.With thegrowingcloud-IoTintegration,thearchitecturalcomplexityincreases,requiringfasterprocessingframeworksbasedoninteroperabilityandreliability.Recentstudies,therefore,focusonthereal-timehealthdata administration, unnecessary transmission, and the implementation of hybrid cloud solutions to enable scalable healthcare solutions (as shown in Figure 1).

The healthcare IoT architecture generally consists of three basic layers [5](1) perception or sensing; (2) the network communication; and (3) application services:

1) PerceptionLayerData-CollectingSensingSystems

This layer comprises identifications and sensing technologies that include RFID, infrared, webcams, GPS gadgetsandbiomedicalsensors[6].Thesesystemsmonitorthechangeoftheenvironmentorphysiology,encode them in digital signals, and prepare them to be transmitted.

2) NetworkLayerDataTransmissionandStorage

Thisisalayerthatsupportswirelessorwiredcommunicationoftheprocessedsensorsignals,eitherlocallyor centrally [5]. Short-range medical communications are often carried out using wireless technologies like Bluetooth, Zigbee, Wi-Fi, RFID and wireless sensor networks.

3) ApplicationLayer

This layer does health analytics and user service provision [7]. The integration ofAI in the work of modern IoThealthcare applicationsisone of the possibilities,which include medical imaging,detecting anomalies,drug discovery, and clinical decision support.

B. ApplicationsofIoT-BasedHealthcareSystems

ApplicationsforIoT-basedhealthcaresystemsimprovepeople'slivesinmanyways,includingas:

- **Remote monitoring,**inwhichwearabledevicesareusedonthepatienttogetpatientdata,localanalytics,and results are delivered to physicians.
- **Physiologicalmonitoringinreal-time,**withcloudandedgecomputing,inwhichcontinuousmedicalmeasurements are stored and analyzed [8].
- **Preventivecare,**inwhichanomaliesassociated withapatternareidentifiedearlyandnotifiedtocliniciansor family members.

C. TypesofMedicalIoTDevicesandSensors

Medical IoT gadgets constantly monitor patient-specific physiological measurements, particularly in places like operating rooms. Such tools are used to check the temperature, blood pressure, respiration rate, and pulseirregularities.TheyalsocontainECGsensorsthatcaptureelectricalcardiacactivity,SpO2sensorstotrackoxygensaturationlevels,andfall-detectionmodules,whichhaveaccelerometersandgyroscopestodetectsudden movementorfall[9].TheseinterdependentIoT-enabledmedicalsensors,combinedtogether(asshowninFigure 2), increase patient safety, clinical efficacy, and real-time diagnostic decision making.

(a) Thermometer (b) Blood pressure (c) Pulse rate

(d) ECG (e) Blood Oxygen Sp0^2 (f) Fall detection

(g) Auscultatory method (h) Oscillometric method

Fig.2.TypesofMedicalMeasurementDevicesandSensors

D. WirelessPatientMonitoringinOperatingRooms

Wirelessmonitoringsystemsovercometherestrictionsoftraditionalwiredsystems,increasingthemobilityof staff, decreasing clutter, and increasing quicker clinical response time [10].Anesthesiologists and surgeons are provided with nonstop access to essential metrics that enhance the predictabilityof the procedure and determine the outcomes.

1) Real-timeVitalSignMonitoring

The parameters being monitored (ECG, oxygen saturation,respiration rate, blood pressure, and temperature) in wireless sensors and sent directly to the clinical dashboards are used to aid in the early diagnosis of complications.

2) SurgicalWorkflowIntegration

Lackofrestrictivecablesenhancestheflexibilityofmovementaswellasfacilitatingproceduresco-ordination amonganesthesia,surgicalandpost-operativeunits.ThewearableIoTdevicesfacilitateasmoothcommunication process and facilitate the interconnection of perioperative care stages.

3) ChallengesinWiredvsWirelessSystems

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E. CaseStudyIllustration:PerformanceEvaluationofMedicalIoTMonitoringSystems

Asmallcase-studyevaluationwascarriedouttotesttheperformancefeasibilityofIoT-enabledhealth monitoringtechnologiesusingwearableandclinical-gradesensorsavailabletoprovethatthetechnologiescould, infact,workinpractice.Thetestwasaimedatmeasurementaccuracy,latencyofdatatransmissionandcontinuousworking time which corresponded to real-world and laboratory conditions.

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The systems and devices comprised heart rate monitors worn on the wrists, commercial energy-expenditure watches, ECG patch monitors, WBAN ECG modules, multi-hop WBAN communication paths and IMU-based falldetectors.Performancemeasurementswerecollatedbasedonpublishedliterature,whichidentifiedindicative capacities during regular use conditions as shown in Table I.

TABLEI.REPRESENTATIVEPERFORMANCEMETRICSOFMEDICALIOTMONITORINGSYSTEMS

Device Type/ Sensor	**Accuracy (%)**	**Transmission/ Detection Latency**	**Continuous Operating Duration**
ECGPatch Monitor (e.g.,Zio Patch) [11]	~95–99% analyzable signal	Detects major arrhythmias within 24–48 hrs; extended detection beyond 48 hrs	7–14 days continuous
Wrist-Worn HR Monitor (Apple Watch, Fitbit,etc.) [12]	<5–10% HR error in controlled activities	Instantaneous sensing;varies with activity	12–36 hours typical
Commercial EE Monitoring Watch [13]	>20% error rate	Nearreal-time reporting	12–24hours
WBAN ECG Module (IEEE 802.15.6) [14]	>97% sensing reliability	<50 ms MAC layerdelay	10–12hours
Multi-hop Medical WBAN Path (ZigBee→WLAN /WiMAX /UMTS) [15]	Reliable routing	Delaydepends on path selection; tensto hundred so fms	Infrastructure powered
IMU-based Fall Detector [16]	92–96% event detection	30–60ms	24 hours

1) AnalyticalInsight

Therelativeanalysisofmedical IoTmonitoringplatformsshowsthattheperformanceofthedevicesin differentcategoriesvaries.TheECGpatchdevicesliketheZioPatchhaveclosetofullycoverablesignalanalysis andextendedarrhythmiadetectiontimeofover48hourswhichmakesthemadependableinstrumentintermsoflong-term cardiacmonitoring[11].HeartratemonitorssuchastheAppleWatchandFitbitarewornonthewristproviding errorsoflessthan10percentoftheheartrateinlabconditions,butwithinconsistentaccuracyacrossactivitytypeswitherrorr atesofmorethan20percent[12][13].ECGmodulesbasedontheWBANandbasedontheIEEE 802.15.6 standard demonstrate sensing reliability of over 97 percent and a latency of less than 50 ms, whichissufficienttomakethemanidealchoiceintermsofphysiologicaldatatransferathighspeeds[14].Atthesametime, ZigBee,WiMAX, UMTS, andWLAN-based multi-hop medicalWBAN ensure reliable routing with thevariability of latencyunder heterogeneousnetwork conditions[15].TheIMU based fall detectorsalso playa part in patient safety by providing rapid event detection and sufficient daily operational viability [16]. Taken together, these findings show that consumer wearables can be useful and scalable in terms of monitoring, but clinicallydesignedWBANdevicesandpatch-basedsystemsmaybebetterintermsofaccuracyandreliabilityto use in continuous and medically critical tasks.

F. ComparativeAnalysisBetweenWiredandIoT-BasedORMonitoringSystems

Thetraditionaloperatingroommonitoringsystemsusingwireshaveanumberoflimitationsthatinhibit clinicalperformance.First,wiredconnectiongeneratescablemessiness,makinginstallationdifficultandlimitingpatientm ovementinanoperatingroom.Onthecontrary,wirelessmonitoringthroughIoTdoesnotrequire physicalwiring,whichallowsinstallationof theequipmentintoanergonomicconfigurationandfreedom of movement around the operating table. Second, conventional systems have poor interoperability of devices, and proprietaryinterfacesinhibitcommunicationbetweensensors[17].Inthemeantime,IoTdesignstakeadvantageof standardizedcommunicationprotocols(e.g.,IEEE802.15.6,HL7FHIR),whichfacilitateaheterogeneous combinationofdevices.Third,wiredsystemsdonotgenerallyprovidereal-timeanalyticalintelligenceand caregiversarethusrequiredtoanalyzethepatientdatamanually.Ontheotherhand,IoTplatformscombinecloud andedgeAI,whichprovideautomatedprediction,anomalydetection,andclinicaldecisionsupport.Fourth,wired monitoring scaling is associated with major hardware change, whereas IoT designs can be expanded with new nodeswithoutchanges[18].Lastly,wiredsystemshaveslowresponsetime,whichiscausedbydisperse accessibilitycomparedtowirelessIoTthatprovidespromptnotificationsandremoteaccess,whichhastens diagnostic care. In general, these variations demonstrate that IoT-based monitoring is more flexible, intelligent andefficientinitsoperationthantheconventionalwiredsystemswhichconfirmtheactualityandprogressinthesuggested framework, comparative analysis summarized in Table II.

TABLEII.COMPARATIVEANALYSIS:IOT-BASEDVS.WIREDORMONITORINGSYSTEMS

Feature / Dimension	**WiredOR Monitoring**	**IoT-Based Wireless OR Monitoring**	**Advantage/ Implication**
Connectivity	Cable dependent	Cable-free, mobile	Wireless systems enhance mobility and reduceclutter in the OR.
Interoperability	Proprietary, vendor specific	Standards based protocols	IoT supports integration with multiple Devices and hospital systems.

Analytics	Manual Interpretation of data	AI-drivenreal-time predictions	AI enables predictive insights,early warnings, anddecision support.
Scalability	Hardwareheavy, expansion difficult	Plug-and-play devices	Easiertoscale and adapt to different OR setups.
Response Time	Delayed, human dependent	Real-time monitoring and alerts	Fasterdetection of critical changes improves patientsafety.
Workflow Efficiency	Restricted by cables and layout	Streamlined, less manual intervention	Reduces staff work load and enhances operational efficiency.

G. SystemArchitectureforIoT-BasedOperatingRoom(OR)Monitoring

The IoT-enabled OR monitoring architecture is designed to support real-time physiological surveillance, workflowoptimization, and predictive decision support [5]. It followsa layered pipeline connecting patient-side sensors to cloud analytics and intelligent dashboards.

1) SensingLayer

It is a layer that gathers patient physiological data and operatingroom context parameters. Patient vitals are constantlymonitored bybiomedical sensors which include ECG, SpO 2,blood pressure, EMG, temperature and respiratory rate [19]. Other context sensors monitor ambient conditions, airflow, equipment status and staff movement.AllofthesensingmodulesworkwithwearabledevicesthatareenabledbyWBANs,whichguarantee the mobility of the patient and the minimum workflow incidence.

2) WirelessBodyAreaNetwork(WBAN)

SensornodescreatealocalWBANclusterwithpatientorsurgicalteam.Thenetworkalsopermitsshortrange low power communication that is compatible with the IEEE 802.15.6 standards thus providing an efficient and safe streaming ofphysiologicaldata.Acontrollerdevice, like a smartwatch or embeddedhub,willcombine data packets and leave the body network to transmit them most efficiently.

3) *GatewayandLocalNetworkingLayer*

The WBAN is linked to IoT gateways that are installed in the OR environment. These gateways are used to carry out local data fusion, preliminary filtering,outlier initial detection and then encryption and sendusing WLAN or 5Gnet works.Example soft Typical gateway elements are edge microcontrollers,medical network accesspoints, and dedicated interface nodes.

4) *CloudIntegrationLayer*

Oncetransmitted,dataisroutedtocloudinfrastructureforlarge-scaleprocessingandstorage.Cloudservices providehigh-capacitystorage,real-timestreamanalytics,andseamlessinteroperabilitywithclinicalsystemssuch as EMR/EHRplatformsthrough FHIRan dHL7 standards[20].This layer enables longitudinal tracking and scalable computation.

5) *AI/AnalyticsLayer*

Deep learning and machine learning algorithms are run on cloud or edge-based systems to come up with advanced insights. These analytics models do vital sign prediction, risk scoring, workflow recognition and anomaly detection. The outputs assist the clinicians in decision-making assistance early warning of patient deterioration.

6) *Monitoring&DecisionDashboardLayer*

Thislayerdisplaysanalyzedinformationinsingleclinicaldashboards.Interfacesshowpatientvitalsigns,ORworkflow indicators,equipmentstatusandpredictivenotifications.Dashboardsareavailablebothonwebor mobile and also give context-sensitive notifications to improve situational awareness and timely intervention.

H. RoadmapforFutureSmartOperatingRooms(ORs)

The development of smart ORs is informed by the incremental use of emerging technologies [21]. An organizedtimelineenableshealthcarefacilitiestodesignbothshort,mid,andlong-termupgradestotheirfacilities to accomplish fullautonomous and intelligent surgical settings.

1. Short-Term(1–3years):5GandWi-Fi7Integration

- Installhigh-speed,low-latency wireless networks,which could be used to carry outreal-time patient monitoring, surgical video transmissions and IoT device connections.
- Enableseamlesscommunicationbetweensensors,edgenodes,andcloudsystemsforfasterdatatransferandenhanced situational awareness.

2. Mid-Term(3–5years):EdgeAIandPredictiveAnalytics

- Implementedgecomputingcombined withAIalgorithmstoprocessdatalocally,reducingresponsetimesand network load.
- Introducepredictive analyticsfor earlydetectionofcomplications,automatedalerting,andimproveddecision support during surgeries.

3. Long-Term(5+years):DigitaltwinsinAutonomousORs

- Createabsolutelyautonomousoperatingconditionsinwhichdigitaltwin modelscanbeusedtosimulatepatient physiology, surgery, and workflow conditions.
- IntroduceAI-basedroboticsupport,environmentaladaptivecontrol,andautomatedsurgicalplanningtowardsthe optimization of results.
- Asaresultoftheconnectionbetweendigitaltwinsandreal-worldoperations,realizecontinuoussystemlearningandself-optimization.

KeyBenefitsoftheRoadmap

- Agradualadoptionoftechnologyminimizestheriskofimplementationbesidesenhancingtheefficiency andsafety of surgical procedures.

- Supportsscalabilityandfuture-proofingofORinfrastructure.
- Allowsproactive,anticipatoryand,ultimately,autonomoussurgery.

I.EdgeComputing&5GIntegrationinIoT-BasedORMonitoring

TheconceptsofEdgecomputingwith5Gnetworksintegrationisanessentialleaptowardminimizinglatency andmakingoperatingroom(OR)monitoringasystemwithrealtimeanalyticspossible.Conventionalcloud-basedsolutions demand sensor data fromwearables or medical equipment to be senttoa remote cloud sothattheyare processedandthiscausesdelaysthatmayaffecttimelyclinicalreactions[22].Edgecomputinghelpsreducethis, by operating data processing nearer to its source, in gateways or local edge servers in the hospital network.

Critical patient information can be sent and processed almost in real-time when combined with 5G connectivity, which provides ultra-low latency (110 ms) and high bandwidth. This supports real-time alerts, predictive analytics, and rapid surgical interventions.

ArchitectureOverview

- **IoT Sensors, WBAN(Wireless Body AreaNetwork).**

Wearablesensorsandsmartmedicaldevicescontinuouslycollectpatientvitals(heartrate,oxygensaturation, temperature) and OR context data.

- **EdgeGateway/EdgeAINode**

On-edge node processing uses lightweightAI algorithms to detect and remove anomalies, remove noise and initial predictions [23]. This limits the amount of data to be transferred to the cloud and lowers the latency.

- **5GNetworkLayer**

5G links with high speed help edge nodes to connect to hospital cloud infrastructure to transmit important alerts and high-definition images on the operation tables with lowlatency.

- **CloudAnalytics&AI**

Aggregateddataissenttothecloudtoperformadvancedanalytics,longtermstorageandAImodeltraining. TheAImodelsofcloudskeeponupdatingedgeAIalgorithmssoastoenhancelocalpredictivecapabilities.

- **Dashboards&DecisionSupport**

The clinicians are able to receive processed insights over dashboards and mobiledevices.Immediate clinical action is possible due to real-time notifications and predictions.

KeyBenefits

- **ReductioninLatency:**EdgeanalyticalfunctionsandAI-baseddecisionsareclosetoreal-time.
- **BandwidthOptimization:**Onlynecessaryinformationissenttothecloud,anditminimizesthenetwork congestion.
- **Reliability&Resilience:**Localedgeprocessingmaintainsmonitoringcontinuityevenifcloudconnectivityis interrupted.
- **ScalableAIIntegration:**EdgeAImodelsarecontinuouslyrefinedbycloudanalytics,balancingcomputational efficiency and intelligence.

J.Interoperability&Standards

Interoperability in OR monitoring based on IoT is provided by compliance with the use of healthcare communicationstandardsanddevicestandards.HL7FHIRfacilitatessmoothinteractionsofinformationbetween the IoTsystems and the hospital EMR/EHR to ensure that the information generated by the sensors matches the clinicalprocesses.WBANcommunicationisregulatedatthedevicelevelunderIEEE802.15.6,whichofferslow- power and dependable communication of physiological data around the patient body. In the protection of the connectionsand data streams,ISO/IECIoTsecurity modelshelp to steer the encryption,identity,authentication, and resilience specifications at the various layers [24]. Together, these standards ensure compatibility, secure communication,andregulatorycompliance,enablingscalableintegrationofheterogeneoussensing,networking, and analytic components in modern OR environments.

III. ROLEOFAIANDMLINORPATIENTMONITORING

AI and ML are transforming the monitoring of the operating room (OR) by allowing predictive analytics, identifying risks at an early stage, and providing clinical decision support in real-time (Figure 3). This changes healthcaretomoreofaproactive,data-driveninitiativeratherthanareactivetreatmentprocesswherealgorithmsexamine ongoing physiological measurements to make appropriate clinical decisions. Figure 3 demonstrates the wayAIrevolutionizestheworkofhealthcarethroughautomatingtheanalysis,enhancingthequalityofdiagnosis, and reducing the efficiency of decisions.

Fig.3.AIImpactonHealthcare

A. RoleofAI-DrivenPredictiveModels

Predictive systems that are based onAI can examine anongoing stream of patient data to detect patterns of deteriorationbeforetheyescalatetocriticalsituations,whichwillaidinearlyinterventionandassistclinicianstoavoidcomplications.ThecapabilitiesalsoimprovewirelessIoTsurveillancebyidentifyingtheexistenceofminor deviations in vital signs and sensor measurements. Figure 4 points to key areas of application in which MLcan servethe fieldofhealthcare suchas diagnosticautomation,diseaseprediction,and adaptabletreatment based on a person:

1) CancerDetection

Deep learning algorithms are used to analyze imaging data (MRI, CT) to estimate malignancies prior to conventional visual analysis. The systems are more useful in detecting microscopic abnormalities in breast and lung cancer, thus enhancing sensitivity and planning of timely treatment.

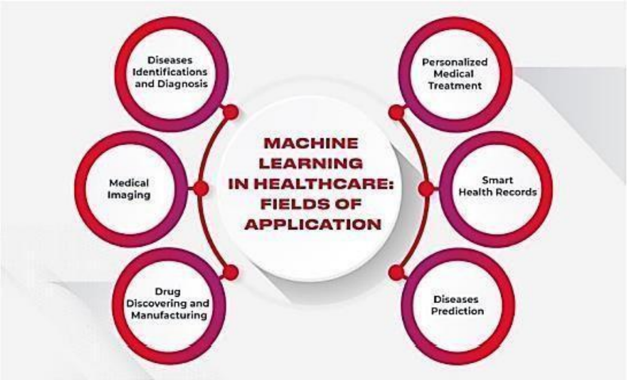

Fig.4.MLinHealthcare

2) CardiovascularConditions

AI systems can evaluate risk based on ECG measurements, blood pressure data, cholesterol levels, and so forth. ML aids in early-stage identification of abnormalities of the heart by detecting traces of pre-symptomatic deviations.

3) Diabetes

Machine learning models assess risk factors which include glucose trends, lifestyle indicators and family history to predictthe onsetofType-2diabetesseveralyearsbefore itoccurs.Personalizeddiabetic treatmentcan alsobemadeavailablethroughAI tosuggestinsulindosechangesandlifestylechangedependingoncontinuous glucose tracking.

B. KeyRolesofAIandMLinORPatientMonitoring

- **Real-timeHealth Monitoring:**The vitalsignstreams(e.g.,ECG,SpO2,BP)areprocessedbyalgorithmsin real-time, and early warnings against abnormal trends are sent.
- **AdverseEventPrediction:**Beforethedevelopmentofcomplicationssuchasintraoperativehypotensionorriskof infection, models predict such complications [25].
- **PersonalizedAnesthesia/DrugDelivery:**AI-guidedsystemsadjustanestheticdosesbasedonphysiological feedback, improving patient safety.
- **ClinicalDecisionSupportSystems:**AItoolsassistwithfluidbalance,analgesiaadministration,andprioritizationof critical decisions in surgery.
- **TaskAutomation:**Documentation,alarmtriage,and workflowcoordinationisautomatized,whichdecreases workload and alarm fatigue of employees.
- **ImageandVideoAnalysis:**Computervisionisusedtoassistsurgery,locatetissues,andevaluatetheperformance ofa surgical procedure with the aid of real-time imaging.
- **ResourceandWorkflowOptimization:**PredictivemodelsestimatethetimespentintheOR,aidinschedulingofORs and improve PACU staffing decisions.

IV. CLOUDCOMPUTINGFORREAL-TIMEHEALTHCARESYSTEMS

The healthcare sector is changing quickly, and operating rooms (ORs) are becoming highly dependent on interconnected technologies to provide safe, timely, and effective care. Cloud computing has become a revolutionary backbone that can be used to access, store and process real time physiological data produced by medicalIoTsystems. It provides a scalable and adjustable systemto handle surgical data[26], to help clinicians in decision-making, and to enable integrated OR processes. The use of a cloud-based access to patient records, sensor data, and imaging reports can enable OR teams to work in real-time, leading to the improvement of intraoperative situational awareness and postoperative monitoring.

A. RoleofCloudComputinginHealthcare

Cloud computing offers the new solution to the old problems in healthcare, notably datacoordination, live monitoring,interoperability,andanalyticsinthesurgicalsettings[27].Inadditiontostorageandscalability,cloud technology enables real-time video streaming of the concentrated surgery, remote patient care, OR automation, and intraoperative data recording, extending clinical results and operational effectiveness [28].

1) HealthcareDataStorageSolutions

Healthcare produces colossal amounts of data about patients, images, and records of intraoperative devices. Cloudbasedapplicationsofferrobustarchivesofthesedatasets,offercentral-storageofsurgeonnotes,anaesthesia data, OR sensor data, and postoperative reports which allows smooth access and continuity of care.

2) ScalabilityandFlexibility

Theworkloadsofsurgeryfluctuateovertimelikesomeemergencycasesorseasonalcases.Cloudarchitecturesenable healthcareorganizationstodynamicallyincreasecomputingand analyticalcapacity, sothatsurgical dashboards, patient feeds [29], orAI-assisted decision systems can remain available during peak operations.

3) SecurityandCompliance

Thehighsensitivityofbothsurgicalandpersonalhealthinformation(PHI)necessitatestheinclusionofmulti-factorauthentication,encryption,intrusiondetectionsystems,andcompliancecontrolsystemslikeHIPAAbythecloud providers.Thesecheckssafeguardintraoperativetelemetry,anesthesiatrackingrecords,andafter-surgerymonitoring records against unauthorized service and assault.

4) DataAnalysisandProcessing

Cloudcomputinghelpswithadvancedanalyticsthatallowclinicianstomakeinsightsbasedonmedicaldata, such assurgical risk predictive modelling and workflowoptimization,aswellasforecasting recovery outcomes. Analytics engines on the cloud assist health professionals in identifying complications at an earlier stage and streamliningdecisionmaking.

5) BigDataAnalyticsforHealthcare

Thecombinationofhealthcarebigdataandcloudcomputingallowstheanalysisofalargevolumeofelectronic health records, data on surgical performance,genomic data, and wearable device streams tomake it possible, leadingto precision medicine and intelligent postoperative care.

6) DataProcessingandMonitoringinReal-time

Cloudsenablereal-time ORmonitoring,telemedicine,emergencyresponse andremotepostoperativefollow-ups.Duringsurgeries,anaesthetistsandsurgeonscanassessvitaltrends,aswellascooperatewithspecialistswho may be at a distance and take measures in real-time using cloud-processed data.

B. ModelsofDeploymentofCloudComputing

There are numeroustypesof cloud modelsused by healthcare systems,including public,private, hybrid,and community clouds, based on regulatory concerns, patient safety considerations, and data sharing considerations [30].

- **PublicCloud:**Cloudprovidersruntheseservices;theseservicesareaccessed viawebinterfaces,e.g.,clinical data archiving.
- **PrivateCloud:**Sensitive workloadofhospitalsisputinitsspecificenvironment, whichprovidesbettercontrol and confidentiality.
- **Hybrid Cloud:**Allowsinterchangeofdatabetweenprivatehospitalsystemsandscalablepubliccloudsystems, which encourages redundancy, compliance and clinical flexibility.
- **CommunityCloud:**Itissharedbetweenorganisationswithsimilarrequirements,e.g.publichealthnetworkstojoint regulatorystandards.

C. TheTrendsthatFavorReal-TimeHealthcareandORSystems.

Thistransformationinhealthcarehasbeenrapid,andthetechnologicalinventionhasplacedcloudcomputing at the top of this invention [31]. The integration of blockchain, the IoT,AI, ML, and other new trends and technologies is being implemented by using cloud technology to improve the outcomes of patients, their data security, and to transformhealthcare. Such innovation has proven that technology can transformhealthcare.

1) ArtificiallyIntelligentandMachineLearning-BasedCloudHealthcareSystems

AIhelpstospeedupcloudanalyticswiththehelpofrealtimeriskforecasting,operatingroomdecisionsupport, automateddiagnostics,andindividualizedaftercare.WiththehelpofAI-poweredcloudservices,imagingstreams are processedandtheirabnormalitiesaredetectedwithhighprecision,enhancingearly-stagediagnosisandintervention.

2) BlockchainasaSecureDataExchange

Blockchain has been shown to improve secure OR data sharing through decentralized storage, secure audit trail, consent control, and the smooth flowof surgical records between medical teams or institutions.

3) *IoTandMonitoring,andAutomationthroughCloudIntegration*

Wearables and OR-based IOT sensors transmit vital telemetry to cloud services [32], which allows intraoperative monitoringin real time, postoperative monitoring, and treatment plan development based on real-time analytics.

V. SMARTMANUFACTURINGANDADVANCEDMEDICALDEVICEDEVELOPMENT

The role of smart manufacturingin the advancement of healthcare technologies is, in particular, the creation ofcompact,very precisemedicalequipmentandminiaturizedsensorsappliedin thehospitalsetting andthe operatingroom(OR).Thissetofmanufacturingparadigmsfacilitatesshorterdevelopmentcycles,greater reliabilityoftherespectivedevices,greateraccuracyinthemanufacturingoftheproducts,andgreatercomponentoperationthatis essentialinpatientmonitoring andclinicaldecisionsupport[33].Digitalsimulation,cyber-physicalmodeling,andadditivemanufacturingaresomeofthetechniquesthatenableengineerstotestthe behavior of their device prior to physical implementation, minimizing the risk and cost involved. Nevertheless, therestillremainanumberofchallengesincludingcybersecurity,thereadinessoftheworkforceandthematurityofthe infrastructure that impedes large-scale adoption.

A. *SmartIndustryintheProductionofMedicalDevices*

ThetechnologiesofIndustry4.0willrevolutionizetheindustryofmakingmedicaldevicesbyproducingsmart factoriesthatcanmanufactureminiaturizedphysiologicalsensorsandinterconnecteddevicesinOR.Industry4.0 principles, as depicted in Figure 5, enable smart manufacturing systems to configure, decentralize, use realtime analytics, and virtualize to produce devices by selfadjusting and optimizing production.

Such systems facilitate building of implantable biosensors, wearable vital signs monitors and OR-based monitoring modules, which utilize the IoTconnectivityto be automaticallycontrolled [34]. Using data analytics andmachinelearning,manufacturingprocessesbecomedynamictodesignconstraints,materialutilization,errors, and device longevitycan be optimized. Smart factories are used to guarantee that medical sensors are veryaccurate, sterile, and have regulatory standards needed in the surgical setting.

Fig.5.SmartProcessingintheMakingofMedicalEquipment

B. *IntelligentManufacturingintheMedicalIndustry*

Inmanufacturing,Intelligentmanufacturingisespeciallyusefultocreateprecisioninstrumentsandmonitoring systems that are needed in ORs, including:

- MiniaturizedECGpatches
- Wirelesspulseoximeters
- Smartinfusionpumps
- Microchipswithdrugsthatcanbeimplanted.
- Surgicalroboticcomponents.

- Resolution-basedimagingsensorsthatarehighresolution.

Robotics and automation are used to speed up the assembly process by producing it with repeatability and minimizingthechancesofcontamination,aswellasincreasingtheprecisionoffabricationbeyondhumancontrol [35]. Under the IIoT integration, machines reporting on their operational status continuously will prevent any interruption by predictive maintenance, guaranteeing the continuity of the production of clinical-grade sensors [36].This is essential to individualized devices, where changes in small form factors impact the performance of the surgery and the outcome of the patients.

C. MedicalDevicesProductionAutomation

The use of automation has now taken center stage in the production of high-risk OR equipment like the anesthesia kits, sterilization-control sensors, endoscopic cameras, and wearable monitors [37]. Decision engines based on AI simplify assembly, calibration, packaging and testing processes and minimize human error and throughput.

- AIs also aid in manufacturingprocesses that identify faults in micro-circuit boards, fluid pathway controls, and sensor housings duringproduction so thatthe systems are compliant with the regulations and clinical reliability.
- Machine vision-basedautomated inspection systemsare usedto confirmthe functionalityofdevices, their sterility, dimensional limits, and safety limits prior to use in the operating rooms.

These intelligent manufacturing innovations, together, help to accelerate the process of innovation, enhance the safetyof devices, decrease their size, and enhance access to accurate monitoringsystems, which are vital to the efficiency and safety of the OR.

VI. CYBERSECURITYANDDATAPRIVACYINWIRELESSMEDICALSYSTEMS

The issue of cybersecurity and privacy is rising in wireless medical systems because uninterrupted physiological data transmission and the growing reliance on IoT-enabled clinical systems are present [38]. The access to confidential data, data manipulation, and interference of wireless channels can be of great danger to patient safety and healthcare integrity. Hence, to maintain stable digital healthcare industries, secure communication, adherence to regulations, and Zero Trust implementation are necessary.

A. ThreatLandscapeofIo-BasedHealthcare

*1) ThreatLandscapeofIo-BasedHealthcare*ThemedicalIoTdeploymentsarebasedonWi-Fi,

Bluetooth, and other short-range protocols that are susceptible to eavesdropping, spoofing, man in the middle attacks (MITM) and jamming. The networks of healthcare are exposed to out-of-date firmware, poor authentication, and improperly configured access points and allow attackers to steal vital physiological information or interfere with patient monitoring.

2) SystemVulnerabilitiesandDeviceVulnerabilities

Mostoftheembeddedmedicaldeviceshavepoorprocessingpower,whichresultsinweakencryption,default passwords, or low-securityfirmware update cycles. Given that IoTsystems are interconnected, a hacked sensor willspreadattackstootherhospitalplatformsandclinicaldatabases,contributingtodistortedmedicalrecordsor terminationofnecessaryservices.TableIIIfurthersummarizestheserisksandthemitigationcontrolsassociated with these risks.

TABLEIII.CYBERSECURITYTHREATSVS.WIRELESSMEDICALSYSTEMMITIGATION CONTROLS.

Threat Category	**ExampleAttack**	**Impacton Healthcare Systems**	**Mitigation/ Control Mechanism**
Network Eavesdropping	Packetsniffing over Wi-Fi	Disclosureof patienthealth data	AES/ECC encryption, TLS/DTLS for securetransmission
Man-inthe-Middle Attack (MITM)	Rogue accesspoint injection	Alteredsensor readings; wrongclinical decisions	Mutual authentication, certificate validation,Zero Trustpolicies
Device Hijacking	Malwaremodified firmware	Lossof system reliability; manipulated treatment cycles	Secure boot, signed firmware, integrity checks
Ransomware & DoS Attacks	Hospitalnetwork lockdown	Service disruption, surgery delays, operational downtime	Network segmentation, intrusion detection/prevention systems (IDS/IPS)
Weak Authentication	Default passwords or credentialtheft	Unauthorized access to monitoring dashboardsor medical records	Strong authentication, multi-factoraccess control
Data Tampering	Sensorspoofing or packet modification	Misdiagnosis or incorrect monitoring interpretation	End-to-end encryption, hashbasedintegrity validation

Physical Device Attacks	Device theft or tampering	Breach of stored patient data	Tamper-resistant hardware, device trackingandaccess logging

B. *CybersecurityFrameworkofWirelessMedicalSystems*

AstrongcybersecurityframeworkisnecessarytoprovidethesecurityofIoT-enabledORmonitoringsystems. This model combines preventive, detective, and corrective actions at both device and network layers and cloud services. Key components include:

1) *ZeroTrustArchitecture(ZTA)*

TheprinciplesofZeroTrustpresupposetheabsenceofimplicittrust,whichmeansthatallusers,devices,and applicationsareverifiedonaregularbasis.ZTAisusedinhealthcareORstomakesurethatsensitivepatientdata is accessed by authenticated devices and authorized persons. Policies include:

- Multi-factorauthenticationofcliniciansandIoTdevices.
- Minimalaccesstodashboards,cloudservicesandlocalnetworks.
- Constantchecksofabnormalbehaviourandunauthorizedaccess.

2) *NetworkSegmentation*

Separatingclinical networks will reduce the effects of possible breaches and separate critical OR equipment with other systems that are not as secure. Usual strategies of segmentation involve:

- EstablishingIoTmedicalequipment,administrationITsystem,andguestvirtualLANs(VLANs).
- Usingaccesscontrolrulesandfirewalltolimitthemovementtothesides.
- Itismonitoringofinter-segmenttraffictoidentifysuspiciousactivityintime.

3) *Real-WorldThreatScenariosandMitigation*

TheIoT-basedORsystemshaveseveralattackvectorsthatmayinterferewithpatientsafetyandworkflow:

- Hospitalfilesareencryptedbecauseofransomwareattacksandsurgicaloperationsaredisrupted.
- WBANor Wi-Fi attacks(Man-in-the-Middle (MITM)) of data integrity threat.
- Hijackingthedevicebyuseoffirmwareexploitsinwhichanattackercanmanipulatephysiologicalreadings.

Mitigation measures are a combination of encryption, intrusion detection/prevention systems (IDS/IPS), secure firmware updates and persistent threat intelligence.Combining these actions, the hospitals will be ableto have resilient, real-time patient monitoring and provide protection to sensitive data as well as guarantee the observance of the regulations, including HIPAA and ISO/IEC 27001.

C. *SecurityFrameworksandProtectionMechanisms*

1) *EncryptionandSecureCommunication*

State-of-the-art cryptography, likeAES, ECC, VPN tunnels, and lightweight ciphers, safeguards the data of patients at rest and in transit. Confidentiality and integrity are reinforced by secure communication frameworks such asTLS/SSL, DTLS,secureMQTTand CoAP. Even batteryconstraineddevices areprovided withlightweight encryption to protect information.

2) *NetworkSegmentationandZeroTrust*

ZeroTrustArchitecture is becoming widespread in modern healthcare, which mandates identity verification, least-privilegeaccess,andnetworkmicro-segmentation.Theuseofintrusiondetectionsystems(IDS)and anomaly-basedlogsincreasestheresiliencetoransomwareandnetwork-widetakeoverattacksonhospitalmonitoringplatforms.

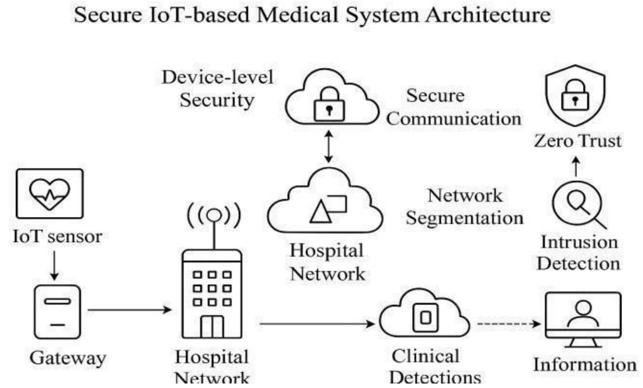

Fig.6.SafeInternetofThings-basedMedicalSystemArchitecture

ThearchitectureshowsFigure6multi-layeredsecuritycomponentssuchasdevice-levelauthentication,secure gateway,encryptedwirelessdata transfer,ZeroTrustimplementation,intrusion detection,segmentedclinical network and protected access to hospital cloud services to clinicians.

D. RegulatoryStandardsandCompliance

The health institutions work within the framework of HIPAA (USA), GDPR (EU), and these frameworks guarantee the confidentiality, integrity, and traceability of patient health information. Medical device security requirements allude to global requirements such as FDA cybersecurity requirements, IEC 62304 (software lifecycle),andISO14971(riskmanagement).Adherenceleadstoreliableworkingsystems,fastpatchingcycles, and strong medical communication systems.

VII. LITERATUREREVIEW

In this section, the main investigations to be discussed are related to an IoT-based healthcare system and its architecture, sensor-based monitoring, remote data transmission, and security issues. Table IV summarizes the works that reveal the significance of continuous, efficient, and reliable monitoring of patients through the IoT.

Wadhwani,MehtaandRuban(2019)utilizeanLSTMrecurrentneuralnetworktocorrelatetheacquireddata inordertoforecastthedisordercausingtheirregularity.Bloodpressure,bodytemperature,andelectrocardiogram(ECG) arethephysiologicalsignalsthataretracked.TheHammingwindowFIRfilterisusedtofiltertheraw ECGdataamongtheobtainedphysiologicalsignals.Toincreasethedata'sdependability,aQRSdetectionwavelettransform algorithm is also employed.This processed data is first saved in the database together with the other two parameters body temperature and blood pressure before being wirelessly sent to a physician along with the patient'slocationinformation.Inthestudy,aprototypepatientmonitoringsystemisdescribed usinganAndroid application with a common interface [39].

SelvarajandDoraikannan(2019)explaintheelementsneededforthehealthcaremonitoringsystem.WBANs are made possible by sensors' ability to collect vital health information.WBAN nodes may monitor blood pressure, heartrate,body temperature,blood sugar levels,EEG, andothermedicaldata.The doctorreceivesthe gathereddataregularly.Thesecurityandprivacyofpatientdata,aswellascontrolflow,aretheprimaryconcerns with wireless communication channels for healthcare monitoring [40].

Akshat et al. (2018) provide an effective strategy that addresses the lack of medical personnel in India by allowingaphysiciantosuccessfullyusetechnologytoremotelycheckapatient'shealth.Crucialhealthindicators suchthe patient's blood pressure, heart rate, body temperature, and blood sugar level, and electrocardiogram (ECG)arecollectedandevaluatedbytheproposedsystemusingsmartdevices,andgalvanicskinreaction.The data is wirelessly sent for further analysis using data analytics using Zigbee IEEE 801.15.4 technology [41].

Wan et al. (2018) introduce a brand-new system for realtime personal health monitoring called WISE (Wearable IoTcloud-based health monitoring system).WISE supports realtime health monitoring by implementing the BASN (body area sensor network) framework.A number of wearable sensors have been integrated, such as blood pressure, body temperature, and cardiac sensors.Second, most wearable health monitoringtechnologiescurrentlyinuserequireasmartphoneasagatewayfordataprocessing,visualization, and transfer, which will undoubtedly affect regular smartphone use.While data collected from the BASN is directly senttothecloudinWISE,analternativemethodforarapiddisplayofthereal-timedataistoinstallalightweight wearable LCD [42].

Abideen and Shah (2017) suggested that ongoing patient monitoring, even when the patient is on the road. Sensitive information is gathered by IoT sensors that are affixed to the patient's body and sent via the patient's smartphonetotheserver.Themethod describedinthisarticleensuresthatIoTsensorsconnecttotheclosestpeer smartphone and continuously transmit data if the patient's smartphone malfunctions.Reports are created whenthe data is examined.

TABLEIV.COMPARATIVEANALYSISOFIOT-BASEDHEALTHCARESTUDIES

Study/ Authors	**Focusofthe Study**	**IoTDevices /Sensors Used**	**Data Transmission Method**	**Healthcare Application**	**Security/ Privacy Concerns**	**Limitations / GapsIdentified**
Wadhwani, Mehta& Ruban (2019)	IoT-based patient monitoring using LSTM for disorder prediction	ECG, temperature, BPsensors	Processed data stored and wirelessly transmitted including location	Continuous remote monitoring viaAndroid app	Limitedsecurity discussion; location data privacyrisk	Prototype only; smallscale evaluation; lacks OR-specific validation
Selvaraj & Doraikannan (2019)	Keycomponents ofWBAN-based healthcare monitoring	BP, EEG,glucose, pulse, temperature	WBAN communication	Periodic reporting to clinicians	High privacy concern for wireless exchange	Security solutions not tested; lacks real deployment scenarios
Wanet al. (2018)	WISE wearable cloud-based healthmonitoring (BASN)	Heartbeat, BP, temperature	Direct cloud upload; optional wearable LCD	Real-time personal monitoring	Cloudexposure risks not examined	Architecturetested at design level; cloudsecuritynot validated in medical settings
Akshatet al. (2018)	Remotedoctor–patient monitoring	ECG, BP, temperature, glucose, GSR	Zigbee IEEE 802.15.4	Rural/remote care support	Not explicitly covered	Narrow geographical context; no scalability assessment; no cybersecurity framework
Abideen &Shah(2017)	Reliable mobile monitoring with peer fallback	Body-worn IoTsensors	Smartphone-based transmission	Emergency	Ensures secure	Focused on continuity, not analytics; lacks

			with peerfallback	surveillance while travelling	connection continuity	hospitalintegration context
Tyagi, Agarwal & Maheshwari (2016)	IoT healthcare frameworks and adoption	General medical sensors	Cloud-basedIoT integration	General healthcare IoT enablement	General discussion only	No empirical validation; conceptual, lacking implementation

Stakeholdersarealertedintheeventofanemergency[43].

Tyagi,Agarwal and Maheshwari (2016) outlines the uses of IoTand discusses some of the key elements and traits of each use.This article has carefully analyzed the role of IoT in healthcare delivery, the technological componentsthatenableit,anditspotential.Acloud-basedconceptualframeworkthatwouldhelpthehealthcare sector adopt IoT healthcare solutions has been put forth [44].

VIII. CONCLUSIONANDFUTUREWORK

Intheoperatingenvironmentcharacterizedbyhigh-acuitysituations,patientmonitoringisthekeytoefficientworkflowandpatientsafety.Thispapersupportstheideathatsurgicaldecision-makingandoperational responsiveness are essentially reinforced through the wireless IoT-based OR monitoring.The suggested system decreasesthetimetosetupandincreasesthemobilityoftheinfrastructurebysubstitutinginflexiblewired infrastructure with interoperable sensor networks, edge-assisted analytics, andAI-driven alerting to enable real- time physiologicalmonitoring.Asemphasizedby quantitative results,there are significanteffects,including quicker clinical response, less complicated wiring, and greater precision in the earlydetection of anomalies.The evaluation concludes that wireless IoTdesigns are not simple replications of the alreadypresent monitoring, but they turn into intraoperative situational awareness and safety assurance.Going forward,future improvements must be guidedby a systematic roadmap,with short-termfocuson the integration ofnew connectivity standards (5G,Wi-Fi7)andbettercybersecurityimplementation;mid-termimprovementsatthedeploymentofedgeAIto enableautonomousprioritizationandfault-tolerantdata processing,andlong-term transformationintosemi-autonomoustofullyintelligentORswiththeabilitytopredictivelyinterveneaswellascoordinateautonomously across robotic systems andvia digital twins to plan surgeries.Altogether, the intersection ofwireless sensing, cloud intelligenceandpredictiveanalyticsmakestheIoT-enabledmonitoringacrucialroutetothesafer,more efficient,andintelligentsurgicalecosystem,andthepresentedstagedroadmapprovidesarealisticwayoffurtherresearch and clinical implementation.

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