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Original Research Article

Internet of Medical Things Application in King Hamad University Hospital

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Abstract

Background*:** The Internet of Medical Things (IoMT) is a network of medical devices and applications that are connected to the internet, allowing healthcare providers to remotely monitor and manage patient health. King Hamad University Hospital (KHUH) is a tertiary care hospital in Bahrain that has implemented various IoMT applications to improve patient care. ***Methods: The aim of this study is to investigate the application of Internet of Medical Things (IoMT) in King Hamad University Hospital (KHUH) and its impact on patient care and hospital operations The study will be conducted at KHUH, which is a tertiary care hospital located in Bahrain. KHUH, accommodates 739 bed in all services. (In- patients including isolation rooms: 348, Out-patient clinics: 242, Other services: 149). That provides specialized medical services to patients from Bahrain and neighboring countries. ***Results*:** The survey results showed that the most commonly used IoMT applications were remote monitoring devices for vital signs, telemedicine platforms for virtual consultations, and electronic health records for patient data management. Healthcare providers reported that these applications were effective in improving patient outcomes, reducing hospital readmissions, and increasing efficiency in healthcare delivery. However, some challenges were identified during implementation, such as technical issues with connectivity and data security concerns. ***Conclusion*:** The implementation of IoMT applications in KHUH has shown promising results in improving patient care and healthcare delivery. However, ongoing efforts are needed to address the challenges faced during implementation to ensure the sustainability and scalability of these technologies. Further research is also needed to evaluate the long-term impact of IoMT on patient outcomes and healthcare costs.

Keywords: Internet of Things (IOT), Healthcare, Hospital Management System, Smart Healthcare.

INTRODUCTON

Internet of Things (IOT) is becoming one of the important topics in the Information Technology (IT) field. It is planned to transfer the real-world objects into virtual objects. It is intended to give the world not only the control of things, but also to learn the status of things [1]. This is clear from the many different disciplines using the IOT such as: education, industry, agriculture, healthcare, and so on. Since a special focus is being directed to the introduction of electronic technological communication devices in different sectors in the governments especially in those of the developing countries. Bahrain is starting to mingle the different technology aspects in its various governmental sections. Ali *et al*., 2017, introduced a framework to help in decision-making regarding the IT infrastructure [2], their proposed framework gives guidance to choose between different technologies. It also helps in estimating how ready is the organization to implement this new technology. Another important sector that experiences the invasion of the usage of computer technology in its domain is the healthcare. The medical sector is one of the essential life sectors that requires a lot of investigation by the computer researchers. Hence, researchers are keeping the healthcare domain as a main

sector for study.

A. Amin (2020), proposed an intelligent advisory system for decision-making based on artificial intelligence (AI) methods to diagnose and give the correct treatment for patients with X-ray images and/or hand written text reports [3]. Moreover, since the AI is a vital field for prediction and machine learning is one of its subsets, then this branch has penetrated in the IOT and cloud environment. This was illustrated when the authors of [4] used the machine learning techniques to predict the user's charging behavior in the cloud environment based on their charging history logs. They presented a model that minimize the number of transactions of charging requests, while maintaining the revenue steady. Therefore, it is important to have different testing actions for the IOT based systems. This was illustrated in [5] where they presented a framework for IOT-based test cases (TCs) prioritization.

Figure 1: Recent IOT healthcare trends

Recent IOT healthcare trends are shown in Figure 1, and wirelessly powered healthcare networks are anticipated to allow real-time monitoring, emergency care, early diagnosis, and an illness of chronic diseases. The storage of medical data, the creation of health records, and the provision of on-demand services to authorized stakeholders all depend on medical servers, databases, and cloud-enabled services. Additionally, it provides a wide range of medical applications, including monitoring of chronic illnesses, rehabilitation, fitness programs, wearable monitoring devices, and geriatric care. Therefore, much medical equipment, sensing devices, diagnostic, and imaging devices can be seen as smart objects or devices that form a crucial component of the healthcare IOT. IOT based healthcare services are anticipated to lower costs, improve patient care, and improve user experience [6, 7]. The practical difficulties resulting from the use and adoption of IoT technologies have recently drawn more attention from researchers and service providers to this sector. Because of this, there are currently several applications, services, and prototypes available. Recent significant themes in healthcare research include, among others, platforms, interoperability, and security concerns [8]. But the Internet of Things is still a young technology, and scientists have many questions about it. On the other hand, IoT integration with healthcare solutions is still in its infancy. Therefore, it is anticipated that many stakeholders who are interested in this field would find great value in having a clear awareness of current research and future directions [9, 10]. The aim of this research to implementing the technology of IoMT in the King Hamad University Hospital (KHUH) to reduce risk and improve the quality of patient care. The HOPE (Healthcare Operating Environment) system, an in house system developed by KHUH, is used to integrate many of the hospital's medical devices, such as patient monitors, ECGs (Electrocardiogram), OR (Operating Room), medical imaging systems, through a network.

HOW IOT IS BENEFICIAL FOR HEALTHCARE

Through tiny wearable devices and ingestible sensors, the Internet of Things has evolved as a ground breaking technology that collects critical bodily metrics from patients and analyzes their pathological data. It

supports a wide range of applications, from implantable medical devices to wireless body area networks and cloud based analytics platforms, and has demonstrated a larger potential for enhancing people's health [11]. Therefore, IoT-based healthcare solutions can be employed in a variety of settings, such as remote health monitoring, chronic disease monitoring and treatment, fitness programs, senior care, and pandemic situations.

The IoT has improved the lives of many patients especially the elderly, by making it possible to continuously monitor their medical problems. A context dependent alarm mechanism gives messages to family members or medical personnel on any disturbance or changes in a person's usual routines, allowing them to take any necessary precautions [12]. This has a significant influence on people who live alone and their families. Different stakeholders are interacting with linked IoT technology in a variety of ways depending on usage and engagement [13]:

- IoT for Physicians - IoT enables medical professionals to work more proactively and attentively. Doctors will be able to choose the optimal course of treatment for each patient and achieve the desired results with the help of the data collected from various IoT devices [13].
- IoT for Hospitals - IoT has made it feasible for various gadgets to assist in regularly tracking and monitoring the patient's health state. However, by employing IoT sensors attached to medical equipment, hospitals can track the real-time location of things like wheelchairs, defibrillators, oxygen pumps, nebulizers, and other monitoring instruments [13].
- IoT for Patients - Regular monitoring of the patient's status and disease diagnosis is made possible by wearable and ingestible sensors. For further examination by qualified medical staff, such gadgets as blood pressure monitors, heart rate monitor cuffs, and wearables like fitness trackers can be wirelessly connected or, alternatively, linked with your smart mobile device [14].

METHODS AND APPLICATION

The aim of this study is to investigate the application of Internet of Medical Things (IoMT) in King Hamad University Hospital (KHUH) and its impact on patient care and hospital operations. The study will be conducted at KHUH, which is a tertiary care hospital located in Bahrain. KHUH accommodates 739 bed in all services. (In- patients including isolation rooms: 348, Out-patient clinics: 242, Other services: 149). That provides specialized medical services to patients from Bahrain and neighboring countries. The hospital has recently implemented several IoMT applications, including remote patient monitoring systems, smart beds, and medication dispensing systems. These applications are expected to improve patient outcomes by enhancing communication between healthcare providers and patients, reducing medication errors, and improving overall efficiency in hospital operations.

KING HAMAD UNIVERSITY HOSPITAL IMPLEMENTING IOT TECHNOLOGY

The implementation of IoT in KHUH involves integrating hospital equipment to the network using Health Level 7 (HL7). This integration allows for the transfer of data between the hospital equipment via network to Hospital Information System (HIS) which is HOPE as shown in Figure 2, allowing for more efficient communication and data sharing. The connection is established using Transmission Control Protocol (TCP), which is a reliable protocol that ensures secure data transmission Figure 3[15].

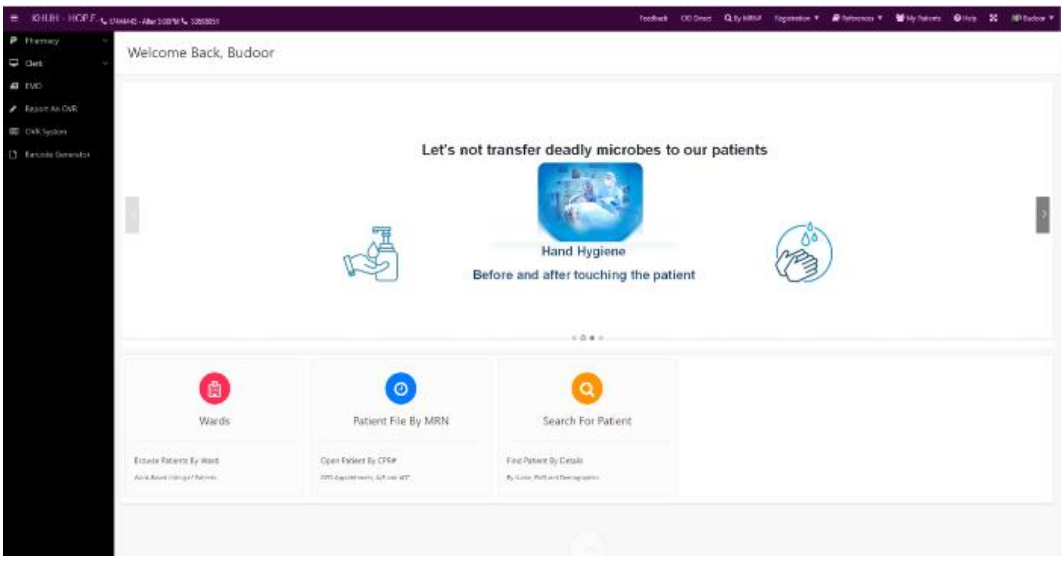

Figure 2: HOPE Interface

The data is then stored on a physical server, which provides a secure location for storing sensitive information. This integration allows for more efficient communication between different departments within the hospital. Additionally, it allows for better monitoring of patient health and medical records, providing better care to patients. Overall, this integration of IOT in our hospital provides a more efficient way to manage patient care and data sharing.

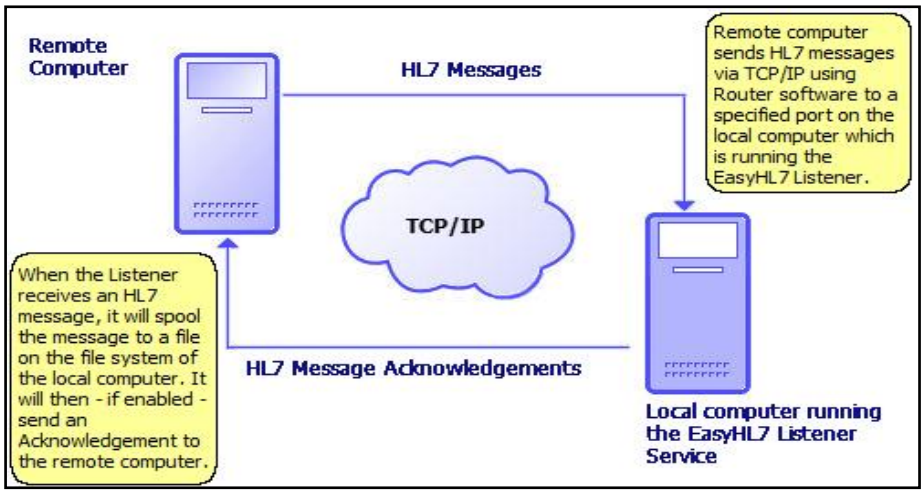

Figure 3: HL7 TCP Connection

Health Level 7

HL7 is a communication protocol used to enable the sharing of data between different medical systems. It allows for the efficient transfer of patient information, such as lab results, orders, and other clinical data, between healthcare providers and patients. Additionally, it can be used to link different medical systems together so that they can exchange data more effectively. This helps to minimize mistakes and enhance patient care. HL7 provides methods for linking orders and results to clinical trials, registering clinical trials, and reporting device-related events. The transaction sets enable the transmission of clinical observations, including but not limited to laboratory findings, patient status and condition measurements, vital signs, intake and output, symptom severity and/or frequency, as well as vital sign measurements as shown in Figure 4 [16].

```
    extension.valueCodeableConcept = MeasurementProtocolTemporaryCodeSystem#AOBP
    "Automated office blood pressure protocol"
* status = #final
* category = ObsCat#vital-signs "Vital Signs"
* code = LNC#96607-7 "Blood pressure panel unspecified time mean"
* code = LNC#96607-7 "Blood pressure panel mean systolic and mean diastolic"
* subject. Display = "OldMan 1234"
* effectivePeriod.start = "2019-10-16T12:12:29-09:00"
* effectivePeriod.end = "2019-10-16T12:42:29-09:00"
* issued = "2019-10-16T12:12:29-10:00"
* performer. Display = "OldMan 1234"
* body Site = SCT#723961002 "Structure of left brachial artery (body structure)"
* device = Reference(BPDevice2-example)
* component[0].code = LNC#96608-5 "Systolic blood pressure unspecified time mean"
* component[0].code = LNC#96608-5 "Systolic blood pressure mean"
* component[=].value Quantity = 120 'mm[Hg]' "mm[Hg]"
* component[+].code = LNC#96609-3 "Diastolic blood pressure unspecified time mean"
* component[+].code = LNC#96609-3 "Diastolic blood pressure mean"
* component[=].value Quantity = 80 'mm[Hg]' "mm[Hg]"
```

Figure 4: HL7 code example

HL7 can be used to streamline the transfer of data between a central station monitoring system and other healthcare applications. This data could include patient information, medical device data, and other health-related information. By using HL7, the central station monitoring system can receive real-time updates

from other healthcare applications, allowing for more efficient and accurate patient monitoring. Additionally, HL7 can be used to send notifications or alerts to healthcare providers when changes in patient status occur [16].

RESULTS

The study focused on the application of the Internet of Medical Things (IOMT) in King Hamad University Hospital (KHUH) to improve healthcare delivery. The results revealed that KHUH has successfully implemented several IOMT applications, including remote monitoring, telemedicine, and predictive analytics. These applications have been integrated with the hospital management system to enable real-time monitoring of patients, remote consultations with specialists, and early detection of potential health issues. The implementation of IOMT applications in KHUH has also brought about several benefits. It has enabled the hospital to provide better and more efficient care to its patients, reduced hospital readmissions, and improved patient outcomes. In addition, IOMT has helped to improve the hospital's workflow and reduced the workload of healthcare professionals, allowing them to focus more on patient care.

The HOPE

The HOPE has a clear and profound positive impact on the way the hospital operates.as shown in figure 5, It streamlines hundreds of business processes across the organization. HOPE is powered by Oracle APEX, which offers unparalleled speed, integration, and security. We now have the agility to rapidly build and evolve our hospital information system in record time on minimal infrastructure, and to provide excellent healthcare more efficiently.

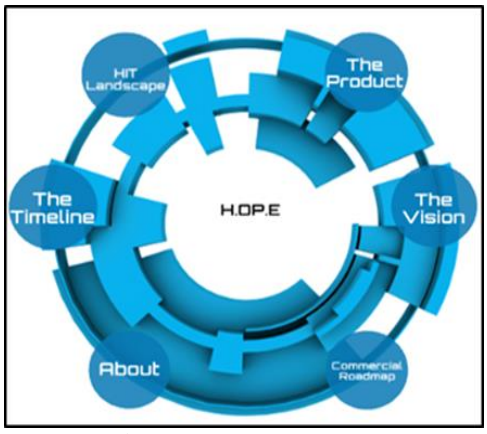

Figure 5: HOPE System

As an example of implementing Radiology department to the HOPE system, workflow shown in Figure 6. This workflow is also being applied in cardiology, Intensive Care Units (ICU), ERD, Gynecology, OPD clinics, operating theater and patient's wards for the comfort of healthcare services, where technician acquired the images on ultrasound and transmits it on spot to send it to HOPE system so the assigned physicians can examine it and study the condition of patient.

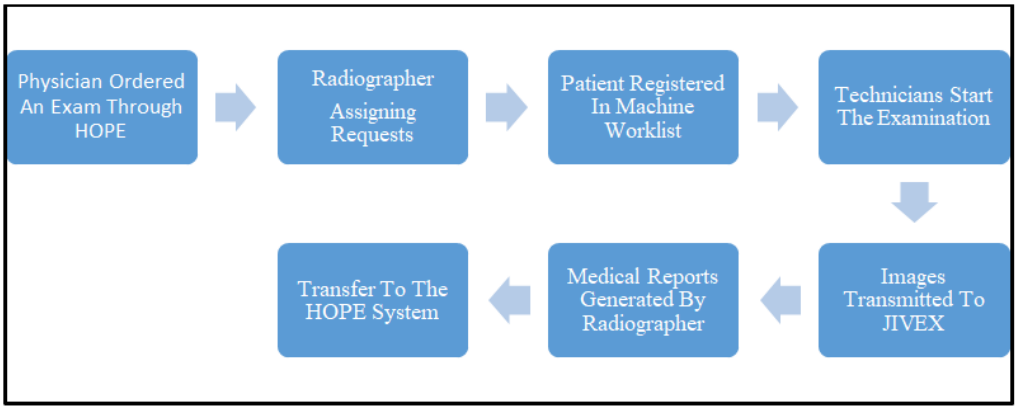

Figure 6: Workflow for radiology department

Another examples of Medical devices which successfully integrated through network to the HOPE system, patients vital sign presented in the Figure 7 shows one of the patients where his vital signs recorded by nurses then the record transmit through network to the system. When the patient admitted in the isolation

room or Intensive Care Unit (ICU) his vital signs and other medical signs are continuously recorded and in each predefined amount of time the data is transmitted to the system as demonstrated in Figure 8.

Figure 7: Vital signs in HOPE

Haemodynamics /Cardiac (Critical Care)

		07	15	30	45	08	15	30	45	09	15	30	45	10	15	30	45	11	15	30	45	12	15
TEMP	°C	37.8																					
ASBP	mmHg																						
ADBP	mmHg																						
NSBP	mmHg	137				143				136				142				143				148	
NDBP	mmHg	78				63				75				78				66				72	
HR	BPM	102	100	107	106	103	102	109	105	103	109	109	105	110	110	106	104	104	104	108	104	107	108
PAP	mmHg																						
CVP	mmHg																						
Rhythm	°C	SINUS TACHY				SINUS TACHY																	
MAP	mmHg																						
RESP-RATE	mmHg	23	17	22	30	25	26	25	28	27	37	27	27	36		27	26	29	26	35	31	32	33
O2Sat		96	94	96	93	92	98	96	96	96	96	97	96	93	95	94	97	98	97	94	95	95	95
RASS-ASSESSMENT																							
RASS-SCORE																							
SEDATION-GOAL																							
SEDATION-MANAGEMENT																							

Figure 8: Patients vital sign recording

When the patient performs an ECG test, the ECG record will be shown in the HOPE system with the date and time of that test Figure 9. The data is transferred from MUSE (Cardiology Information System) to HOPE system through the network. MUSE Cardiology Information System is a database management system to view the cardiac data recorded [16] Figure 10. HOPE system is integrated with MUSE and gives the physicians direct access to these data. All ECG records can be viewed and printed with the feature added by the HOPE system.

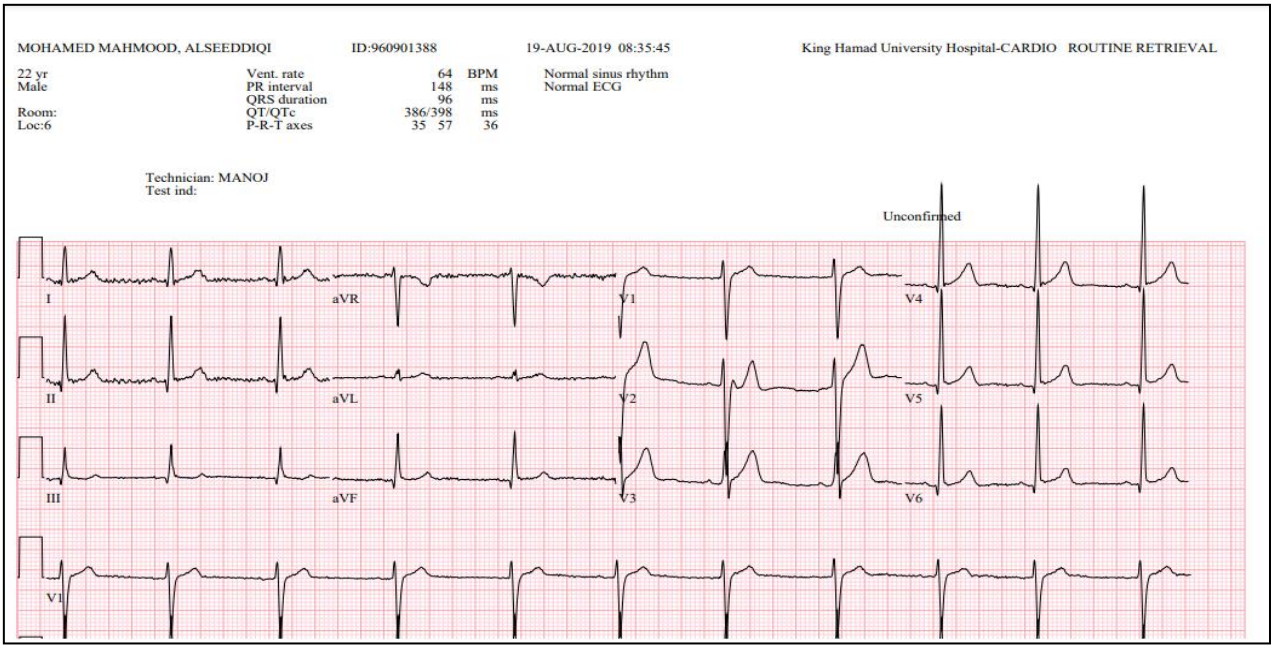

Figure 9: ECG Report

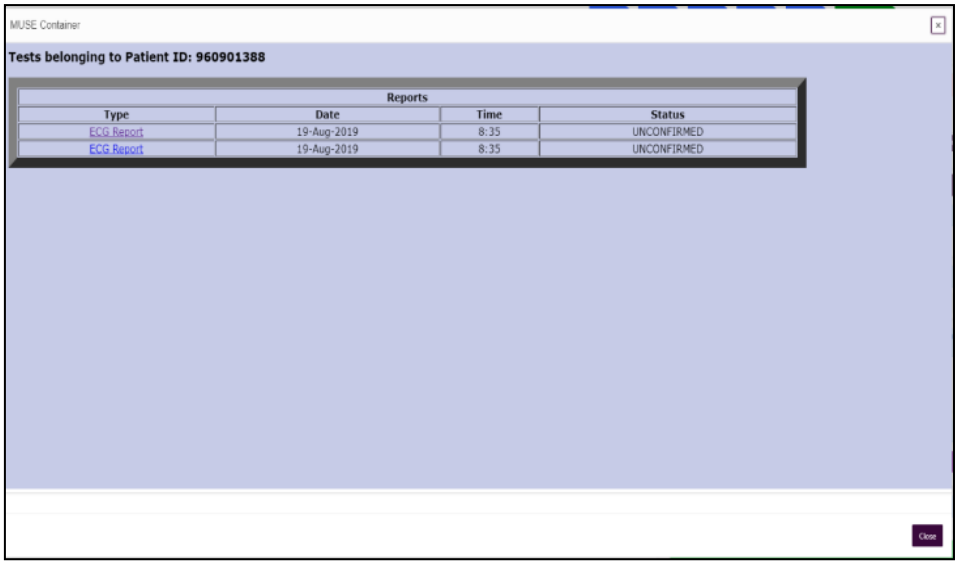

Figure 10: ECG Muse Interface

Operation Room (OR) integration system as shown in Figure 11 simplifies the work in the operating theaters by combining the video management system and sounds Input and Output (I/O) system to the Hospital Information System (HIS) and stored in the servers. This system will help the surgeons in improving their performance by minimizing their movement during the procedure and by integrating the OR system to HIS which will allow the physicians to review the recorded cases on their disk for training and review purposes as shown in Figure 12 [18, 19].

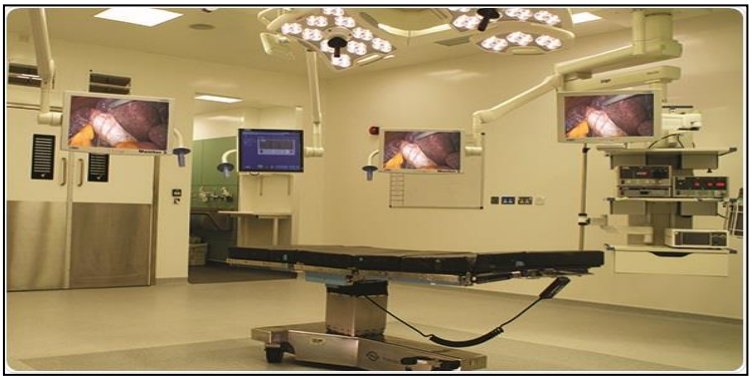

Figure 11: OR system

Figure 12: The AIDA system records and captures the procedure/patient information

DISCUSSION

The Internet of Medical Things (IoMT) is a network of medical devices and applications that are connected to the internet, allowing for real-time monitoring, analysis, and communication of health data. King Hamad University Hospital (KHUH) is a leading healthcare institution in Bahrain that has implemented IoMT applications to improve patient care and outcomes. One example of an IoMT application used in KHUH is remote patient monitoring. Patients with chronic conditions such as diabetes or heart disease can wear wearable devices that track their vital signs and send the data to healthcare providers in real-time. This allows doctors to monitor patients remotely, adjust treatment plans as needed, and intervene quickly if necessary. Another IoMT application used in KHUH is telemedicine. Patients can consult with doctors remotely using video conferencing technology, eliminating the need for travel and reducing wait times. This is particularly useful for patients who live far from the hospital or have mobility issues. IoMT applications also help with inventory management and asset tracking in hospitals. Medical devices can be tracked using sensors, ensuring they are always available when needed. This reduces waste and improves efficiency in hospital operations.

However, the study also identified several challenges associated with implementing IoMT solutions in a hospital setting, such as data security, privacy, and regulatory compliance. These challenges need to be addressed to ensure that patient data is protected and that the hospital complies with regulations governing healthcare data.

CONCLUSION

The Internet of Medical Things (IoMT) is a technology that connects various healthcare systems through computer networks in order to transmit and receive data. This type of communication is done through wired or wireless connections between two or more medical devices. The integration of medical devices through networks increased during the COVID-19 pandemic as a way to help prevent the spread of infectious diseases, reduce contact with isolated patients, and improve healthcare services. The objectives of implementing the technology of IoMT in the King Hamad University Hospital (KHUH) are to reduce risk and improve the quality of patient care. The HOPE system, an in-house system developed by KHUH, is used to integrate many of the hospital's medical devices, such as patient monitors, Glucometers, ECGs, and medical imaging systems, through a network. The use of IoMT in the healthcare sector, including at KHUH, has the potential to greatly improve patient care and hospital management through real time monitoring, early diagnosis, and the provision of on-demand services to authorized stakeholders. However, it is important to also consider the potential risks and challenges, such as data security and privacy, when implementing these technologies.

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