Development of Edge-IoMT Computing Architecture for Smart Healthcare Monitoring Platform

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***Abstract*— The age of virtual healthcare has created new opportunities to reconsider traditional methods for the preliminary medical examinations and clinical doctor-patient appointments. The COVID-19 pandemic has forced medical systems for strengthening online services in each medical field. Implementations of novel digital health technologies will dramatically reduce inessential hospital visits of patients for early diagnosis. Moreover, the telehealth based medical platforms will allow the medical services to be time- and cost-effective with convenient media for both patients and doctors. In this study, an internet of medical things (IoMT)-based smart healthcare monitoring platform architecture is proposed to remotely telecommunicate with optimized bandwidth efficiency and latency for a rapid decision-making process management for preliminary diagnosis in a virtual environment. The proposed edge-IoMT computing architecture framework will allow filtering and squeezing of raw medical data of the real-time video footage of the patients with functional algorithms.**

Keywords—Smart healthcare, Internet of medical things, healthcare monitoring platform, edge computing, teleopthalmology

I. INTRODUCTION

The virtual healthcare consultations have received immense popularity with the COVID-19 pandemic. Recent advancement in the internet of medical things (IoMT) drastically deviated healthcare consultations to the IoT-based digitalized healthcare systems [1-3]. In the traditional method, the accessibility and scale of medical service could not meet the needs of patients on a daily basis. Recently, telemedicine technologies are supported by interactive video consultation via secure cloud servers with high resolution monitoring systems using advanced wearable medical devices and sensors in healthcare industry [4]. With advances in communication technologies, IoMT is certainly changed aspects through the extended online network. In recent years, IoMT-based medical wearable devices have fostered extensive utilization of transforming virtual healthcare systems [5]. Moreover, the teleoperation, a remotely operated technology, becomes a viable tool for remote management of healthcare technologies. The novel healthcare platforms have the potential to allow medical processes to be more time efficient and portable for easy accessibility to even in the most rural areas [6].

Many efforts have been made to design and build a convenient and reliable architecture for IoMT-based health monitoring systems [7-12]. These medical systems shape gradually with the rise of smart portable wearable devices in biomedical industry. The vast majority of these devices are used in the fields of preliminary medical examinations by collecting ECG, EEG, blood pressure, body temperature, respiratory rate, motion activity, glucose recognition data which are mainly concerned with the preservation of health by providing early examinations to discern the acuity of other complications [13].

The key parameters of the smart healthcare monitoring platform can be classified as follows. The data security is one of the vital parameters for privacy requirements. The data authentication is the critical parameter with related access control. Low-latency is the operational requirement for the connectivity. Lastly, the data sharing capability improve the accuracy of the platform [14]. The smart healthcare monitoring platform that will be created must bear at least these key parameters.

This study focused mainly on the development of the edge-IoMT computing architecture for a smart healthcare system. A novel edge-IoMT computing architecture is proposed to enhance bandwidth efficiency and reduce latency. A functional smart healthcare monitoring platform is developed for revealing an effective real-time monitoring system that provides patients a personalized online service-oriented architecture for highly accurate diagnostic solutions under distance medical examination condition.

II. BACKGROUND & RELATED WORK

Research in digitizing healthcare procedures are uprising with the recent COVID-19 pandemic. Some advancements in the literature are stated in Table 1 for comparison purpose.

Table 1. Studies on IoMT-based healthcare system

Study	Objectives	Methodology
Villarrubia et al. [7]	Patient tracking and monitoring via Holter device at home	Indoor tracking throught accelerometers and wifi networks.
Kaur and Jasuja [8]	Heartpulse rate and body temperature monitoring	Remote health monitoring throught cloud.
Pham et al. [9]	Daily basis health monitoring via collecting motion and audio signals at home	Medical data collecting using environmental and wearable sensors at home.
Hegde et al. [10]	COVID-19 pre-screening, fever and cyanosis non-contact detection	Forehead and lip regions real-time detection and segmentation. Temperature estimation via infrared camera image
Greco et al [11]	Real-time motitoring for detecting anomalies in physiological parameters	Edge stream computing architecture with distributed implementation of HTM algorithm for anomaly detection
Queralta et al. [12]	Cardiovascular and diabetes monitoring for fall detection system	Fall detection system implemented on Edge Node

III. Fundamental Infrastructure

The smart healthcare platform infrastructure should mainly have three important layers. These are the perception layer, network layer and application layer [5].

The perception layer is built to collect required data from the patients. The perception layer framework enlarged with the novel innovative wearable IoMT-based devices enabling privacy-aware remote early clinical examinations. The real-time video-mediated consultations are paired via IoMT-based wearable devices which produce live footage for the doctor that can control the health monitoring system integrated with the healthcare platform. IoMT-based wearable devices are key modules for video consultation systems. They are widely deployed in various settings and allow remote access and live video on a built-in structure.

The network layer allows both patient and doctors a separate interface supplied with subsystems that gather medical record and additional information, which gets stored in the secure IoT-based cloud database. The network layer works as the backbone of the smart healthcare platform for accurate real-time telehealth system. The transmission and reception of the collected medical data occurs through the network layer. Thus, this layer is the fundamental infrastructure layer for the smart healthcare platform [15].

The application layer is dedicated to the management of the smart medical platform with custom interfaces and role-based control panels for decision-making process on diagnosis. The patient visit management, real-time video consultation and early diagnosis and further examination take place in this layer of the platform architecture.

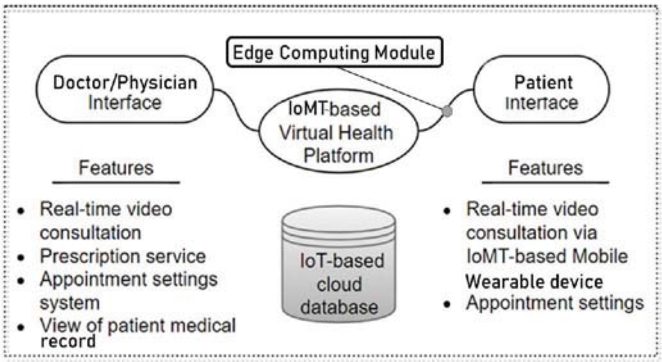

Fig. 1. Subsystems and features of the edge-IoMT computing architecture for a smart healthcare system

IV. Smart Platform Modules

The proposed smart healthcare platform relies on the components responsible for monitoring, processing, storage and personalized system compatibility. Two fundamental modules have been created for the smart platform architecture. These are edge computing unit module and cloud infrastructure module as shown in Fig. 2.

Due to the number of connected sensors and the huge amount of streaming data, the network layer can quickly overload. Thus, the edge-IoMT computing architecture is selected for smart healthcare monitoring platform. The preferred edge computing module facilitates reduced communication latency and data streaming. The platform is maintained with edge-IoMT computing healthcare framework. [16-17]. Furthermore, cost-efficient healthcare monitoring platform is created via integrating edge computing algorithms and healthcare system.

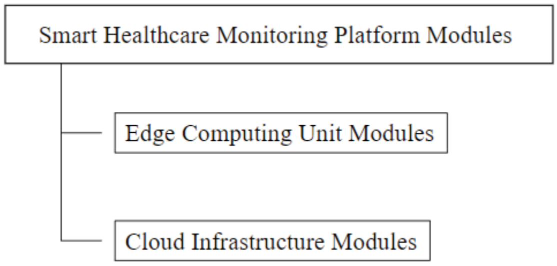

Fig. 2. Main modules of the smart healthcare monitoring platform

The private cloud server creates a network between wearable device and physician with stored/recorded real-time footage and additional patient information. The cloud server transmits the medical information to physician via streaming server in a secured manner. The footage is digitally converted and encoded to receive a medical stored data. This procedure follows to the web server that monitors it to the virtual healthcare platform (VHP).

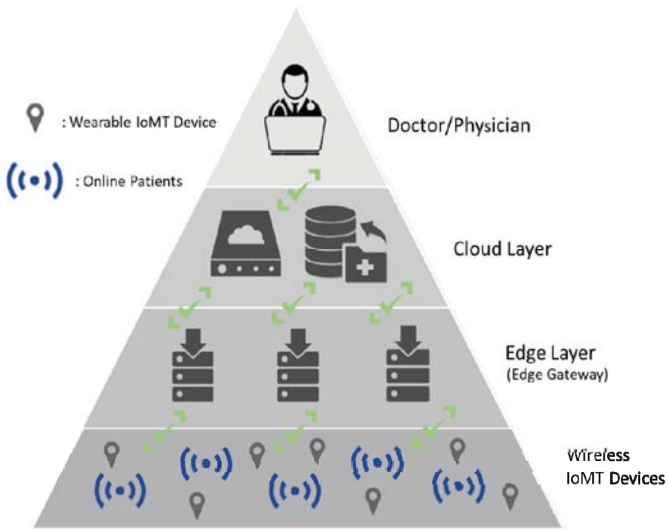

Fig. 3. Smart edge IoMT-based healthcare platform layers

In the edge computing, video clipping or video quality reduction methods can be utilized in order to squeeze the video/audio data which are received from the wearable IoMT-based devices. Different adaptive algorithms can be implemented to boost the bandwidth efficiency of the network through squeezing video/audio streams. This methodology provides tackling the extra bandwidth which is redundant for video/audio streaming data. Additionally, bandwidth adaptation algorithms can reduce transmitting redundant audio/video records.

The proportion of the saved bandwidth can be easily calculated using the Eq. 1. In the Equation 1, B_p represent the bandwidth consumed by a video/audio stream and B_n represents the bandwidth after applying video quality reduction or video clipping. The percentage bandwidth saved when the quality of this video is reduced or the video is clipped is simply calculated by Eq. 1[18].

$$\text{Bandwidth saved (\%)} = (1 - B_n / B_p) \times 100 \quad (1)$$

In order to gain optimized bandwidth, the smart healthcare platform architecture can be equipped with selectively permeable smart data filters and edge device regulation for a sound network infrastructure. The optimization solution is described with min C_i (ω, α), where ω denotes wireless channel bandwidth allocation profile and α denotes offloading strategy profile for each patient (i). The optimized solution affects the lifespan of the smart healthcare monitoring platform [3, 6].

V. Smart Platform Architecture

Edge computing and IoMT-based wearable devices are the two significant modules that functionalize the smart healthcare system architecture. Integrating these modules provide reduced overall network latency with low bandwidth- and power-consumption. The requirements of smart healthcare platform can be satisfied through the edge computing and cloud layers. This approach allows the medical record computations closer to the wearable IoMT-based medical devices to obtain minimized network traffic with reduced overall latency.

We have designed an edge-computing based IoMT architecture for the healthcare monitoring platform. The architecture of edge IoMT-based healthcare monitoring platform is illustrated in Fig. 4. As illustrated, a layered IoMT-based architecture is employed in the monitoring platform. Three layers were defined as the user interaction IoMT-based wearable device layer, edge computing unit layer and the cloud layer, respectively. All the layers communicate via Wowza Streaming Engine and Wi-Fi connection. The detailed hardware and software sub-systems are provided in the previous study [19].

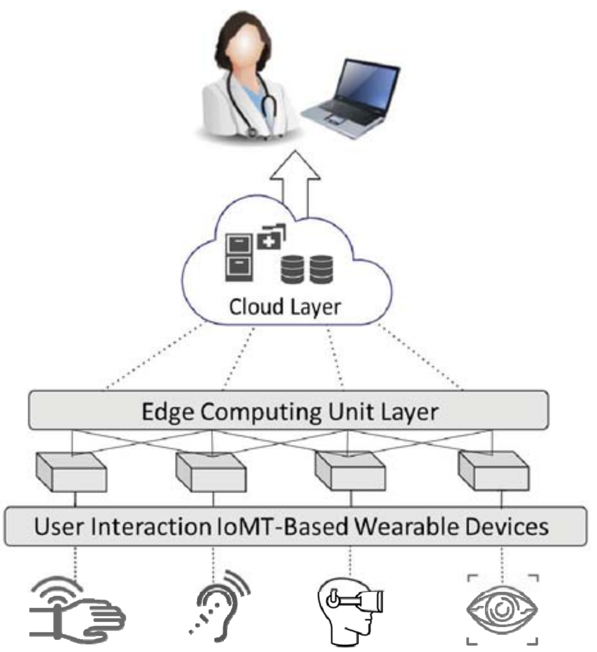

Fig. 4. Smart IoMT-based medical device platform architecture

As a case study, a wearable IoMT device for eye examination is manufactured to test the capability of smart telehealth edge IoMT-based healthcare platform. On one side, the patient connected to the platform via wearable device through the Wi-Fi network. On the other side, ophthalmologist examined the patient's eye from different locations. We note that the operating system of the ophthalmologist-in-the-loop telehealth platform worked successfully during the preliminary eye examination demonstrations.

The patient recorded eye video data are filtered and processed before forwarding to the cloud layer through the edge computing layer. The physical interfaces provide the required core data for the physician using the C# code. Some of the patient and wearable IP device related information in the code are given in Fig. 5.

```
{
    _context.PatientHardwareInfos.Add(new PatientHardwareInfo
    {
        PatientUserId = user.Id,
        IsDeleted = false,
        CameraIp = ipAddress,
        StreamAddress = streamAddress,
        CameraType = CameraTypes.Axis,
        StreamName = sName
    });
    affectedRows = await _context.SaveChangesAsync();
}
```

Fig. 5. Patient related code segment in the IoMT layer of the platform.

The edge computing layer is composed of IoT gateways. It communicates with the other two layers of the smart healthcare system providing accelerated streaming traffic. It collects the medical data from the wearable device layer and transmit them to the cloud layer after processing. Edge computing layer performs analyzing the medical data at the patient location. The cloud layer receives the medical data processed from the edge computing layer. This layer stores the medical data in the database of the cloud system. The stored data is optimized at the cloud layer with the computation at the edge layer with minimized cloud computing.

VI. Conclusion & Future Work

In this study, an edge-IoMT computing architecture is proposed for real-time video consultation of the smart healthcare monitoring platform. In the developed functional architecture, an IoMT-based medical device is integrated to the healthcare monitoring platform through the edge computing module. The accuracy of the established platform is validated via preliminary demonstration using the wearable IoMT-based eye examination device. It is observed that smart healthcare monitoring system works successfully with the proposed edge-IoMT computing architecture. The main contribution of this work is to demonstrate the functionality of the developed architecture. Furthermore, it is unveiled that the healthcare platform utilizes real-time video streaming data in each layer using Wowza Streaming Engine. The 5G communication technology will bring novel advancement for the communication infrastructure of the developed smart healthcare platform. In the near future, the proposed healthcare platform architecture will be implemented in different real-life medical case studies for examining and early diagnosing in order to demonstrate its applicability in varied medical services in remote locations.

ACKNOWLEDGMENT

I would like to thank MD Ali M. Hacımustafaoglu and Ophthalmology Department in MedicalPark Goztepe for assisting this project with the essential medical information required in the project. Author thanks to Dr. A. Yerden for supporting with the server network solution and O. Cakin for assisting with the software development process of the smart platform.

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