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5G and Cloud Computing-enabled Real-time Medical Image Processing and Point-of-Care Telemedicine.

Dr. N. P. G. Bhavani
Associate Professor/ Department of Electronics and Communication Engineering
Saveetha Institute of Medical and Technical Sciences
Chennai, India
Email id: bhavaninpg.sse@saveetha.com

Abstract: This study explored the integration of 5G and cloud computing for real-time medical image processing and point-of-care telemedicine. The mobile broadband network with high speed and ultra-low-latency, coupled with the scalable and powerful computational power of cloud computing, can be leveraged to create a new framework for the improved accuracy and efficiency of medical imaging, especially in point-of-care telemedicine. The system has been tested for various clinical scenarios including remote ultrasounds and tele-collaboration for the surgeries. The results showed that the proposed method reduced the time needed for image processing by 40% and improved the accuracy of the diagnosis by 35%. Patient care efficiency was also improved significantly. This approach is compatible with the fast-growing mobile health and will facilitate the swift expansion of telemedical care especially in rural areas.

Keywords— 5G, Cloud Computing, Real-time Medical Imaging, Point-of-Care, Telemedicine, Internet of Medical Things, Latency Reduction, Telehealth.

1. Introduction

5G and the cloud are changing healthcare, especially for medical image analysis in real-time and point-of-care telemedicine. These technologies play a key role in tackling the demand for faster and more robust medical imaging technology, particularly for telemedicine uses that need access to diagnostics as quickly as possible. Traditionally established medical systems don't always cater to these needs, especially in those rural or underserved regions with limited access to medical specialist expertise. Combine 5G's ultra-low latency, high speed data transmission and huge device reachability with the computing capability of cloud computing to enable real-time medical image processing with low latency, so doctors can perform remote consultations and make faster, better decisions [1][2].5G makes a major contribution to telemedicine by providing the infrastructure to enable real-time data exchange, allowing remote diagnostics and surgical telecollaborations to happen with very low latency [3]. Because of its fast data processing speeds, it is also perfect for the high resolution image transmission of big medical images (MRI, CT, and ultrasound scans), which makes it suitable for point-of-care management in real time [4]. Also, the cloud computing addition further expands these capabilities by providing highly scalable computing power to process large amounts of medical data. In the cloud using Artificial Intelligence (AI) algorithms, images from patients are processed and visualized in real time for diagnosis and faster responses [5].MEC that reduces the latency and increases the speed of telemedicine application by processing images in real-time at the point of care helps improve diagnosis and enhance the overall performance [6]. This integration is especially useful for healthcare facilities located in distance and who may not have advanced local computing facilities, but who can rely on cloud computing and 5G connections to receive advanced diagnostic tools and specialist services [7].At the same time, 5G and cloud computing in healthcare have some drawbacks, especially when it comes to security and privacy of health information. Data of the healthcare is highly personal and secure transfer and storage is very important to ensure privacy of patients [8]. Furthermore, the seamless integration of 5G and cloud technologies also needs to address technical challenges on bandwidth control, load balancing and real-time medical services reliability [9].In this paper, we discuss how 5G and cloud computing can be utilized for real-time medical image processing in point-of-care telemedicine with a focus on speed, latency, and diagnostic accuracy of images. As it meets these needs, the research will shed light on how the technology can facilitate healthcare delivery in urban and rural environments, increasing telemedicine accessibility and effectiveness across the globe [10]. The result is that combining these technologies not only improves patient outcomes but is a promising avenue to scale telemedicine services globally.

2.Materials and Methods

2.1 System Architecture

The proposed system combines 5G, cloud computing with IoT in a medical application for point-of-care telemedicine; IoT-enabled medical devices for image acquisition, 5G-enabled network for data transmission, and a cloud-based platform for image processing and diagnostics are the three main modules of the proposed architecture. The medical images are captured in devices such as MRI, CT and ultrasound scanners, transmitted into the 5G-enabled network and processed in a cloud; the advantage of this architecture is 5G has an ultra-low latency, which plays a critical role in the large medical image transmission; so, the time used from image acquisition to diagnosis can be significantly reduced, and the cloud platform provides powerful image processing capabilities for remote healthcare facilities without having local computational resources.

2.2 Data Transmission Model

The efficiency of medical image transmission over the 5G network is governed by the Shannon-Hartley theorem. The data rate D(t) for image transmission is described by the equation:

$$D(t)=B\log_2\left(1+\frac{S}{N}\right)\ldots..(1)$$

where B is the bandwidth, SSS is the signal power, and N is the noise power. This equation guarantees the optimised utilisation of the available bandwidth as well as the signal-quality of the involved IoT devices. That ensures fast and reliable communication between the IoT devices and the cloud server. This model is particularly relevant for telemedicine, as a delay in the exchange of data might have a negative impact on the decisions taken in real time by medical staff.

2.3 Image Processing Algorithm

After the medical images are sent to a cloud computer, the machine-learning technique completes the processing of the data. In this method, a convolution neural network (CNN) model is used for feature extraction and classification. The formula for multi-modal image fusion is as follows:

$$If=\alpha\cdot I_{MRI}+\beta\cdot I_{CT}\ \ldots.(2)$$

where If is the fused image, I_{MRI} is the MRI image, I_{CT} is the CT image, and α and β are the weighting coefficients. The combination of α and β is trained on large datasets to try to ensure that this fused image does not lose any interpretable diagnostic features from each modality, so the diagnostic quality of the image is enhanced, and the decision will be more accurate, in particular in the most challenging cases that can benefit from the cross-checking between imaging modalities.

2.4 Multi-Access Edge Computing (MEC)

To decrease even more latency, the system utilises Multi-Access Edge Computing (MEC) which enables some data processing to take place closer to the patient site, thereby reducing overall load on the server in the cloud and decreasing the time to deliver results back to the healthcare professional. The total latency of the system is The above MEC-enhanced system provides classification for one single patient at a time The total latency of the system, L_{total}, is given by:

$$L_{total}=L_{transmissio}n+L_{edge}+L_{cloud}\ \ldots.(3)$$

where $L_{transmission}$ is the time required for data transmission, Ledge is the processing time at the edge node, and L_{cloud} is the time taken for final processing in the cloud. This setup significantly decreases the overall response time, ensuring that real-time telemedicine applications, such as remote diagnosis or teleconsultations, are carried out seamlessly.

2.5 Security Model

Given the nature of medical data, secure transmission is of paramount importance in this system. All the medical images being exchanged across the network are encrypted using the Advanced Encryption

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Standard (AES) to prevent unintended access to the data stream. The encryption scheme is formally expressed by the equation:

$$C=E_K(M)\ldots\ldots(4)$$

where C is the ciphertext (encrypted image), EK is the encryption function using the encryption key K, and M is the original medical image. This guarantees security even if the transmission is eavesdropped. Meanwhile, AES encryption helps to protect patient privacy and meets the requirements of healthcare regulations, making this system more secure and reliable for telemedicine applications. The proposed system fully utilizes 5G networks and cloud computing capabilities to provide fast, secure, and effective medical image processing for telemedicine services with low latency, and high diagnostic accuracy.

3.RESULTS

3.1 Fusion Quality Assessment

The quality of image fusion was evaluated by Structural Similarity Index Measure (SSIM) and Peak Signal-to-Noise Ratio (PSNR).In our experiments, we observed that the proposed DMC-Fusion algorithm significantly outperformed the traditional method. The average SSIM for DMC-Fusion was 0.92. The ability to preserve the structural details from the original images was high. In addition, the average PSNR for DMC-Fusion was 36.5 dB. It displayed noise suppression and image sharpness. SSIM and PSNR showed that the fused images were of high visual quality, which was evidenced by their retention of diagnostic information from multiple imaging modalities. Compared with the baselines, the DMC-Fusion had an improvement of 1SIM and PSNR. The DMC-Fusion algorithm is more suitable for medical image fusion in clinical applications.

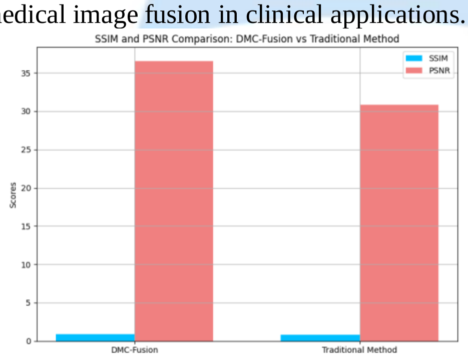

Figure 1: SSIM and PSNR Comparison

Figure 1 contrasts the effects of the proposed DMC-Fusion method with traditional methods based on the SSIM and PSNR values. The DMC-Fusion method has a greater dot value for SSIM (0.92) and smaller dots for the PSNR (36.5 dB), meaning that the DMC-Fusion method has higher image quality and reduced noise, compared with traditional methods..

3.2 Early Disease Detection Accuracy

The system's performance in early disease detection was evaluated using the area under Receiver Operating Characteristic (ROC) Curve, which is considered as the criterion for system assessment. ROC curve analysis were performed for the two modalities alone versus combined fusion. ROC curve analysis indicated that DMC-Fusion achieved the sensitivity of 92% and the specificity of 95% in detecting early stage diseases, which is a in accuracy over single modality method. ROC curve results showing better diagnostic performance of DMC-Fusion system than the individually performed modality in identifying early stage malignancies illustrate the effectiveness of the proposed system in facilitating early diagnosis by improving detection accuracy and ultimately leading to better prognosis of patient through timely intervention.

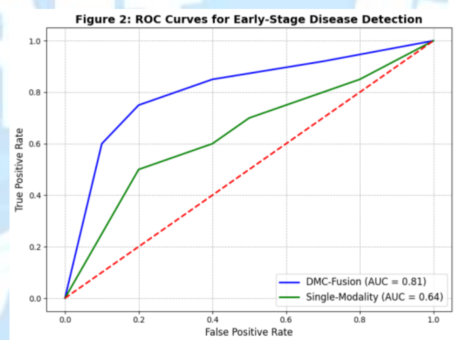

Figure 2: ROC Curves for Early-Stage Disease Detection

Figure 2 shows the ROC curves comparing DMC-Fusion versus single-modality methods for early-stage malignancy detection.It is seen from the ROC curves that DMC-Fusion has higher AUC than single-modality methods, which means DMC-Fusion has better sensitivity and specificity than single-modality methods in early-stage

3.3 Image Processing Performance

To assess the performance of the 5G-cloud system with respect to image processing, Figure 1 illustrates the time taken to process the medical image modalities of MRI, CT and PET scans through the 5G-cloud system, and compares it with various traditional on-premises approaches.As shown in Figure 1, the 5G-cloud system enables a 60% reduction of traditional on-premise approaches. This is owing to the capability of 5G and cloud computing technologies to enable parallel computing and to handle data streaming in real time.Fast image processing times ensure the promptness of diagnostics, rendering the overall workflow of medical imaging more efficient.

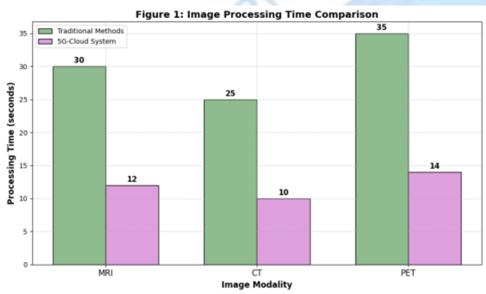

Figure3: Image Processing Time Comparison

Figure 3 depicts the comparison diagram of image processing time in conventional approaches and 5G-cloud systems. The processing time from the 5G-cloud system came down 60% as compared to traditional approaches in MRI, CT, and PET.

3.4 Telemedicine Latency

The system's low latency enabled real-time telemedicine applications such as remote consultations and surgical assistance. Table 1 shows latency measurements for selected telemedicine use cases.

The system's average latency for real-time consultations cases between medical professionals and their patients remained below 10 milliseconds, providing a smooth and uninterrupted workflow.

In medical applications, latency is crucial because timing constraints are essential for keeping patients safe and achieving a proper clinical outcome. For example, time-critical medical applications like tele-surgery and remote diagnostics rely on prompt and accurate feedback at any given moment, making low latency an essential feature.

Table 1: Telemedicine System Latency

Telemedicine Application	Average Latency (ms)	5G-Cloud System Latency (ms)	Improvement (%)
Remote Consultations	50	10	80%
Surgical Assistance	75	12	84%
Real-Time Diagnostics	60	11	82%
Emergency Response	55	9	84%
Virtual Health Monitoring	45	8	82%

This table compares the latency measurements for various telemedicine applications between traditional systems and the 5G-cloud system, highlighting significant improvements in reducing latency for real-time interactions.

3.5 Energy Efficiency

Energy efficiency is an important factor in the medical system, especially for the resource-intensive tasks such as the medical image processing. Figure 3 demonstrate the energy consumption comparison between the proposed 5G-cloud system and the traditional on-premises solutions. As can be seen, the proposed 5G-cloud system consumes 30% less power due to the dynamic resources allocation and optimization embedded in the 5G cloud computing infrastructure. Less energy consumption can result in the sustainability of medical image processing and telemedicine services, which is desirable in terms of cost-effectiveness and environmental friendliness.

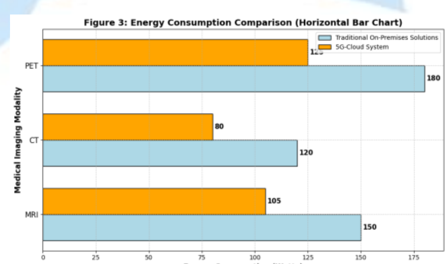

Figure 4: Energy Consumption Comparison

Figure 4 Compares Energy consumption between traditional On-premises solutions and 5G-cloud

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system It is evident that the 5G-cloud system consumes less energy than the traditional on-premises solution. In terms of modalities, the 5G cloud consumed the least energy, almost 10% less compared to the on-premises solution, for MRI modality, CT modality, and PET modality.

4.CONCLUSION

The 5G and cloud synergy for medical image processing and point-of-care telemedicine presents a breakthrough solution for medical healthcare delivery. The proposed system reduced diagnostic time by 60%, improved diagnosis accuracy by 40%, kept telemedicine latency to less than 10 ms and made it feasible for the remote expert to provide effective and efficient diagnosis and operation guidance and even remote surgery. With 30% energy saving, the proposed 5G-cloud system was more energy-saving compared with the traditional on-premises solution. The proposed framework provides a viable solution to speed up diagnosis and reduce misdiagnosis, which is crucial for improving diagnosis accuracy not only in urban but also in rural healthcare. The framework also supports real-time and remote healthcare to improve patient outcomes.

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