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A telemedicine platform empowered by 5G mobile networks for Tunisian rural places

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ABSTRACT

A telemedicine platform needed to be developed to address the various challenges faced by patients in rural areas, such as the lack of specialist doctors, the distance to healthcare and the time spent accessing it, which can present a risk to their lives, especially for those with chronic illnesses. For its realization, we used Laravel 11, a framework that offers powerful features for building modern, high-performance applications. To enable seamless real-time communication, we integrated Laravel reverb, a robust package supporting live interactions, updates, and notifications. The database uses MySQL 8 in combination with PHP 8.2, ensuring performance, scalability, and reliability. The strengths of our systems compared with existing Tunisian platforms are real-time interaction between patient and doctor thanks to 5G, ensuring the transfer of data and access at the same time, real-time communications such as video and audio calls, live notifications and instant messaging.

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1. INTRODUCTION

Rightly speaking, the term "telemedicine" was first used in the late 18th century [1]. This was one of the first reports reported in the early 20th century when electrocardiograph data was transmitted over a telephone line [2]. Nowadays, the practiced and known telemedicine began in 1960.

It is important to note that communication technology has evolved significantly; the telegraph has been replaced by the widely used smartphone. The connectivity has evolved from morse code to the Internet and cellular networks [3]. So, a direct correlation between technological advances, connectivity and the development of telemedicine has been registered. Since the twentieth century ended, an era of information has colored the scene. An information revolution is lived over many new technological products.

Among these novelties, one can cite the medicine sector where noticeable progress was introduced. Many acts like medical imaging, modern tools, and remote consultation have appeared. To prove this progress, we were interested in discussing the Telemedicine application. This constitutes modern technology, and it covers a wide range of healthcare services that can be provided at a distance, including consultations, diagnosis, monitoring, and treatment [3]–[5]. Based on the communications sector's live progress, Telemedicine exploits a variety of communication technologies such as video conferencing, mobile apps, and wearable devices. These are used to connect healthcare providers with patients remotely and randomly located. One can overcome barriers to access to healthcare sites everywhere. A great advantage is particularly offered to rural or underserved areas having limited healthcare infrastructure.

Let's note that there are diverse types of telemedicine software, depending on the application [4]. These can be classified as synchronous telemedicine software and asynchronous telemedicine software. The Synchronous telemedicine software type enables real time services via audio and video calls with live interaction between patients and doctors [4].

However, the Asynchronous telemedicine software does not require live interaction between patients and healthcare providers but enables services such as data storage or transfer [1]. Patient information is exchanged between doctors, one of whom is usually a specialist. This information may include medical images, videos, reports and medical records. The specialist can assess the case. According to his availability, he provides a diagnosis or opinion. Telemedicine can become more efficient by overcoming the critical factors/problems which are: time and distance.

We are trying to develop a modern tool that provides equal access to care, as a solution that facilitates the interaction between patients and medical specialists to fight the delay of access that causes most death cases. This is frequently noted for the poor social category. So, the idea keeps seeing how one can design a platform to monitor their daily condition. This will mainly concern solving the delay problem noted for geographically isolated zones. Many obstacles cause time waste that directly affects their health. So, the idea is to create a platform that will facilitate needed interactions for patients and health professionals. Being accessible to the platform it will provide synchronous and asynchronous services. This will be an added development factor compared to other existing platforms. Our main objective aims to promote health in Tunisia and to fulfill regional disparities as lived by some Tunisian zones. The objective of this paper is to present the design and implementation of such a platform, highlighting its architecture and demonstrating its effectiveness in facilitating remote consultation.

We propose a developed platform designed to overcome numerous difficulties in the healthcare sector in rural areas. Section 2 presents background and related work. For that, the state of the art and particularly the evolution of telemedicine, 5G's advantages offered, Tunisia's health sector and impacts of the COVID-19 in our country will be given. The relation with telemedicine will be discussed. Section 3 will be concerned by methods, architecture and components of our platform. An overview of used technologies and a remote consultation will be proved. Section 4 will give results and discussions. Future directions and challenges will be also shown. The paper will be termed by a conclusion and a consulted references list.

2. BACKGROUND AND RELATED WORK

2.1. Evolution of telemedicine

Telemedicine is different from other medical advances or progress: it is medicine at a distance. At the crossroads of two different worlds - medicine and information and communications technologies (ICTs) - it embodies a new form of remote medical practice; we can talk about a comprehensive and historical view of telemedicine from ancient practice to the present time [4]. From 1940 to 1970, the most important events of this period were asynchronous telemedicine, remote radiology, transatlantic transmission, the use of television for medical education, and the devices used were radio and telephone. Connections are achieved via radio waves. Major events from 1970 to 2000 are the definition of telemedicine, synchronous telemedicine, computers, and the origin of the Internet [5].

Telemedicine in critical care, and the application of space technology to rural health. The devices used during this period were telephones, televisions and computers. Connections are made via television lines, telephone networks, satellites and space technology. These 30 years are characterized by significant innovations in connectivity and devices that laid the foundation for modern telemedicine [2].

From 2000 to 2020, the most important events of this period were mainly available on the internet, and are generally available, on mobile devices, smartphones, electronic health records and telemedical companies' revolution. Devices available during this period are computers, mobile devices, smartphones and telemedicine peripherals and devices. Connectivity is realized via the Internet, broadband, and mobile network. These years were characterized by the rapid development of technical hardware (smartphones, tablets, and telemetry), software (mobile applications), and connectivity (mobile phones, broadband). Various telecommunications and peripherals have been developed to facilitate remote control. With the smartphone revolution, consumers were able to access medical care through their handheld devices. Like many other sectors, medical care is beginning to move from physical facilities to virtual hospitals [6].

As technology advances and curiosity continues to grow among engineers, clinicians and researchers, the future offers immeasurable opportunities for telemedicine. Telemedicine improves access to care, promotes collaboration and education, supports family-centric care, and has a positive impact on healthcare costs. The main drivers of telemedicine over the last decade are recent advances and the increasing availability and use of ICTs by the population [7]. In addition, 5G technology plays a huge role in the evolution of technology given its multiple benefits [7], [8].

2.2. Advantages offered by 5G in the medical sector

5G networks provide higher data rates [7], an important technical capability of 5G wireless communication is high data rates [9] in the range of 1-10 Gbit/s in real-world networks [10]. This is also an increase of a hundred times over 4G technology [11]. Latency reduction [7], compared to 4G round trip time 10 ms [12], 5G aims to reduce latency to round trip time 1 ms. This is about a tenth reduction [3]. In healthcare, this reduction in network communication latency enables remote control robots for medical or primary care in addition to extended and virtual reality applications that require fast request/response cycles [13]–[16].

The basic function of 5G is to be able to support billions of devices such as sensors, connected wearables and accessories [17], and other growing smart devices that require connectivity [3], [18]. Common devices connected to these networks include smartphones and smartwatches running health-related apps, as well as wearables that enable real-time health monitoring and fitness tracking. In addition, to better availability and geographical coverage, next generation 5G systems provide virtually 100% network availability in addition to full geographic coverage, regardless of user location [6].

The International Telecommunication Union (ITU) issued a recommendation in September 2015 under reference ITU RM.2083 [19]. It divided the 5G use case into three main pillars and defined the requirements for international mobile telecommunications (IMT) 2020 (5G) from the perspective of advanced IMT (LTEA). The three main pillars of 5G are as follows [17]: i) Enhanced mobile broad band (eMBB): That is, very high-speed mobile communications. This is in line with previous generations of mobile telephony and is a response to the increasing use of mobile data; ii) Massive machine time communication (mMTC): *i.e.*, Communication between objects, the internet of things falls into this category, for example, smart city with sensor networks to manage different services; and iii) Ultra reliable low latency communication (uRLLC): Communications for which reliability and response time are essential. There must be no communication failures or interruptions, and transmission must be as fast as possible [20]. Due to these generation benefits, it has brought about the evolution of telemedicine [11], [13].

Fight against medical deserts: The healthcare sector suffers from many problems [19], including for example, lack of general practitioner (GP) in rural areas, bed closures, aging populations and increasing chronic illnesses. This is where connectivity and 5G come into play [13]. For example, drones can help rural patients, and telemedicine is regularly cited as a medical desert solution, especially to facilitate the monitoring of chronic diseases [11]. Also, use of remote sensors and surveillance devices to provide access to world-class medical care for patients living in remote areas. The use of video conferencing or telemedicine facilities can bridge geographical gaps and provide quality care to poorly serviced communities [17]. A study conducted by the Department of Veterans Affairs (VA) made significant advances in the treatment of chronic illnesses using telemedicine. In his study of more than 17,000 Veterans Affairs patients, after enrollment in the program, nursing bed days were reduced by 25%, hospitalizations were reduced by 19%, and average satisfaction was 86% [21].

Telemedicine and augmented reality, surgical operations in 5G: surgery also benefits from the power of 5G [12], [22]. 5G greatly improves the transmitted images [23] and reduces delays. Surgeons can also be supported by augmented reality. Doctors wearing augmented reality glasses will receive information that would not have been accessible without this device. A feat was achieved in 2017 with shoulder prosthesis.

Connected objects as a preventive measure [18], [20]: The use of connected objects is also planned to speed up the return home after hospitalization [22]. These objects come into play for the elderly or people unable to move in the context of remote medical monitoring. The goal is to ensure that everyone can benefit from the best possible medical services. The first demonstration of a Shanghai-based 5G intelligent medical application took place in Huashan Hospitals, and 5G, was used for live transmission of high-resolution surgery 20 km away, along with real-time remote surgery instructions and guidance [23], [24].

2.3. Tunisia's health sector

The Tunisian authorities are preparing several national strategic plans, the latest of which is the National Plan Digital Tunisia 2020 with a budget of 5.5 billion dinars for the period 2014-2020. The strategy aims to make Tunisia an international digital hub and to promote ICT as a key vector for the country's socio-economic development. However, in 2020, only 25 of the strategic objectives were not achieved at the project idea stage [6]. Tunisia has now displayed the plan of "Digital Tunisia 2025" which intends to promote the digitization of education and the transition to e-government [25].

In Tunisia, general hospital's number was 12 in 2013 and has grown to 23 in 2021. The number of inhabitants for a doctor is measured at 769 in 2014 and 744 in 2021, according to the Ministry of Health [26]. A program called Expresso on Radio Express FM on March 5, 2024 [27] touched on doctors' migration to Tunisia, with the presence of the general secretary of the Tunisian Doctors' Deanship, who spoke about the reasons for doctors' migration and the problems involved. He said that for medical interns who are not

entitled to certain specialties (they are not among the first), the state has given them the right to obtain a specialty on condition that they practice in interior areas. After training in the specialty, they did not respect the condition and did not practice. Among 200 specialists, only between 40 and 45 were working in interior areas. The general secretary of the Tunisian Doctors' deanship explained that the number of immigrants could mean that there would be no specialists in Tunisia in the future (5.20). Telemedicine platforms are helpful in telemedicine advancement and contribute to overcome many difficulties facing healthcare access in Tunisia.

2.4. Existing telemedicine platforms in Tunisia

In Tunisia, there are several examples of telemedicine platforms facilitating interaction between doctors and patients. We can cite telemedicine.tn [28], Tobba.tn [29], DocNet.tn [30], Med.tn [31], and Wic-doctor [32]. They offer services that differ from one to the next. Some platforms offer synchronous services, others offer non-synchronous services, and some offer both. The challenge is to provide real-time services.

2.5. Impacts of the COVID-19 in Tunisia and its relationship with telemedicine

Today, several services are developing online in Tunisia. The scope of these services is very wide and extends to e-learning, e-business and e-government. It is worth noting that the use of these e-services varies by population and even within populations. Some people improve their health status by using these services, while others cannot. During the COVID-19 containment, people have been forced to turn to the digital world and the issue of digital technology use has taken center stage. Some will continue to work, study, buy and sell goods, have fun, and access e-government, and others will not be able to do so even if they are well-equipped. There are no studies on the digital technologies use in Tunisia. The study by the National Institute of Statistics did not take this dimension into account [6].

In Tunisia, improving e-health systems is essential to enable healthcare decision-making and provide better quality care to patients. However, despite the increasing digitization of the healthcare sector, some challenges to digital transformation remain [6]. Sadok *et al.* [33] identify several challenges in Tunisia, including the lack of a policy agenda, structural reforms, and coherent investment programs, as well as market regulation affecting the development of telemedicine and e-health. During COVID-19, great progress was made in overcoming these obstacles. Mansour and Salem (2020) [34] point out that the COVID-19 crisis has accelerated the digital transformation. Digitization is the key to continuous development. Tunisia should invest in the e-health sector and increase the use of digital tools.

3. METHOD

We are trying to develop a modern tool that provides equal access to care, as a solution that facilitates the interaction between patients and medical specialists to fight the delay of access that causes most death cases. This is frequently noted for the poor social category. So, the idea keeps seeing how one can design a platform to monitor their daily condition. This will mainly concern solving the delay problem noted for geographically isolated zones. The principal components of the proposed system are the patient's medical record, 5G and the telemedicine platform.

3.1. Telemedicine platform

The telemedicine platform facilitates interaction between doctors and patients providing such services guarantees patient healthcare access easily. Patient information is exchanged between doctors, one of whom is usually a specialist. This information may include medical images, videos, reports and medical records, enabling the specialist to assess the case according to availability and provide a diagnosis or opinion. Consultations patient-doctor can be Text-based via real-time chat box which is ideal for situations where patients have limited bandwidth and real-time video calls may not be viable. What is more, patients may also prefer text-based consultations to interactive ones for reasons of confidentiality. Also, it provides audio and video calls. Real-time telehealth services help maintain the patient-doctor relationship, enabling providers to interact face-to-face with patients to assess, diagnose and treat health problems.

The data could be sent to the specialist within minutes. Patients should receive prescriptions for the necessary medication and advice to follow for their health case. Our platform could be publicly and freely accessed.

a. Communication infrastructure: This includes high internet connectivity 5G mobile networks are a vital element in the system to ensure the smooth operation of our system and guarantee the satisfaction of both healthcare specialists and patients with its services.
b. Data storage and management: the platform should include robust data storage and management capabilities to store patient data securely.

3.2. Implementation of a prototype telemedicine platform

The system is considered as a platform that connects many patients with many doctors via server, the platform use case diagram is presented in Figure 1. New technological tools which are used will allow on the one hand optimizing the safety of patients by reducing the time of intervention during the occurrence of various events. On the other hand, this will improve the patient's comfort when he is not unnecessarily moved.

The platform presents real-time video, instant messaging, live notifications and electronic health record (EHR) access. In addition to that among its features and functions we mention Appointment Scheduling, and file sharing the platform allows for the sharing of medical images, test results, and other relevant documents between healthcare providers and patients and secure messaging, healthcare providers and patients can communicate securely through the platform, ensuring privacy and confidentiality.

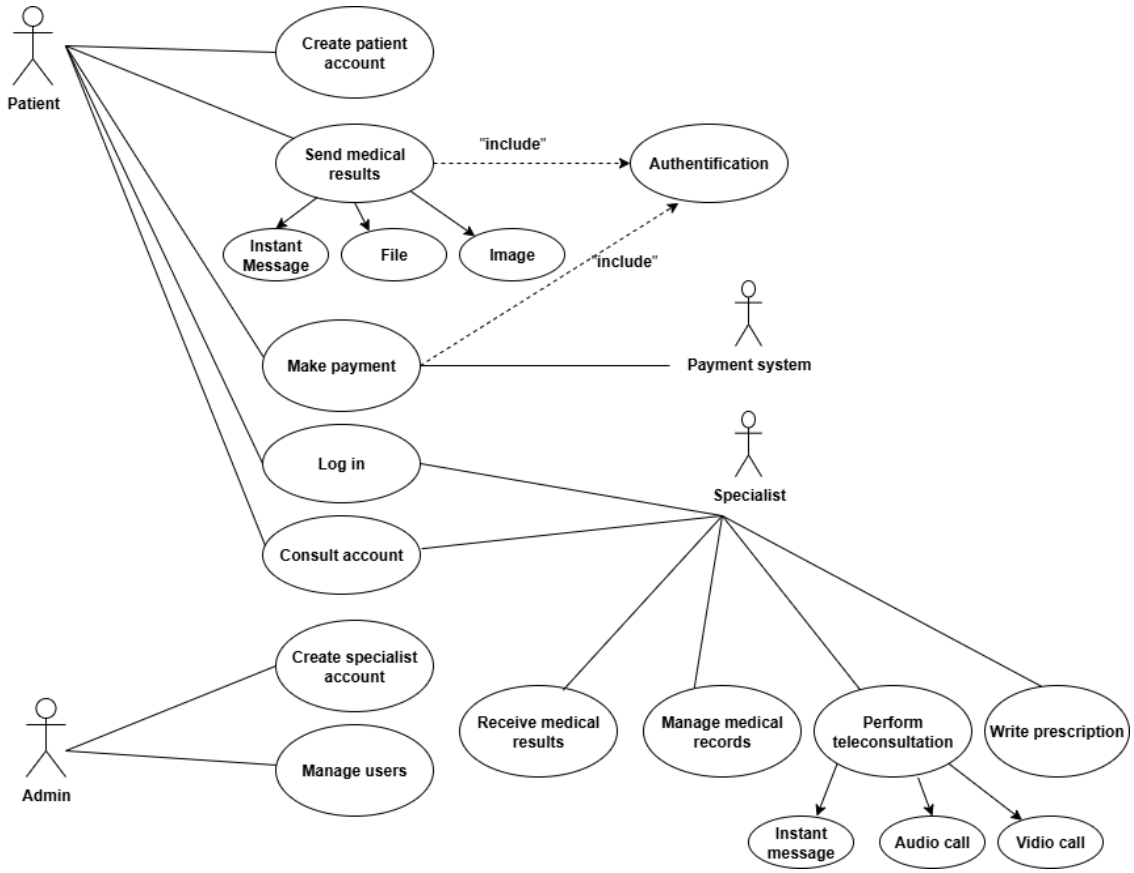

Figure 1. Platform use case diagram

3.3. Overview of our platform technologies

Patients are still not reassured by the services behind the screen, especially when it comes to their health. They are more reassured by seeing their doctor. That is why we're always looking to provide services that improve what already exists. The platform provides real-time services, such as video calls for patients who prefer face-to-face interaction and instant messaging for patients who prefer text-based consultations to interactive ones for reasons of confidentiality to fight against the main obstacle between the patient and the doctor which is the long time to have an appointment. The doctor will be notified following a request from a customer. Only doctors can initiate a video call if necessary, depending on the patient's condition for further organization. To realize these services, the platform relies on the power of Laravel 11, Laravel Reverb and PHP 8.2. In the next paragraph, we will dive deep into the architecture, features, and benefits that make this platform with the services below a standout solution in the market.

3.3.1. Backend

The backend of our platform is built on Laravel 11, a robust and feature-rich PHP framework that provides a sturdy foundation for our server-side logic. By using the latest version of Laravel, we have been able to take advantage of its cutting-edge features, improved performance, and enhanced security measures.

Laravel 11 framework offers powerful features for creating modern, high-performance applications. These include its controllers, which enable business logic to be managed in a structured, modular way. Routes facilitate the management of URLs and corresponding action. Migration also simplifies database management.

One of Laravel 11's main strengths is its expressive syntax and modular structure, developers can code faster and more efficiently. What is more, security is a major concern for any company. Laravel 11 incorporates robust security mechanisms, session ID management and secure queries. Scalability another major advantage of Laravel 11. Its flexible architecture lets you develop scalable applications capable of handling increased workloads without compromising performance.

3.3.2. Real-time communication

We have integrated Laravel Reverb, a powerful real-time communication package, to facilitate seamless real-time communication between our users [35]. This allows our application to deliver instant updates, live notifications, and interactions, creating a dynamic and engaging user experience. Laravel Reverb's advantages for real-time Communication are:

a. Instant messaging: Laravel Reverb enables us to build real-time chat functionality, allowing our users to communicate instantly and effortlessly within the application, fostering a more engaged and connected user base.
b. Live notifications: with Laravel Reverb, we can deliver live notifications to our users, keeping them informed about updates, events, and important information without the need for page refreshes, enhancing the overall user experience.
c. Collaborative experiences: the real-time capabilities of Laravel Reverb enable us to create collaborative features, such as real-time document editing, whiteboarding, and shared workspaces, fostering seamless teamwork and productivity among our users.

3.3.3. Database and scripting

The latest version of MySQL 8 coupled with the advanced capabilities of PHP 8.2, powering our data storage and processing. This combination provides unparalleled performance, scalability, and reliability, ensuring that our application can handle even the most demanding workloads with ease.

3.4. Demonstration of remote consultation

The objective is to promote and improve health conditions in Tunisia and to cover medical deserts everywhere. A demonstration of the prototype platform showcases its capabilities in facilitating remote consultations between patients and doctors. Only doctors can make video call consultations for more organization, then when one of them sends a message it appears in both chat boxes, shown in Figures 2 and 3, also, real-time services offered by this platform include instant messaging, video calls, file sharing and live notifications.

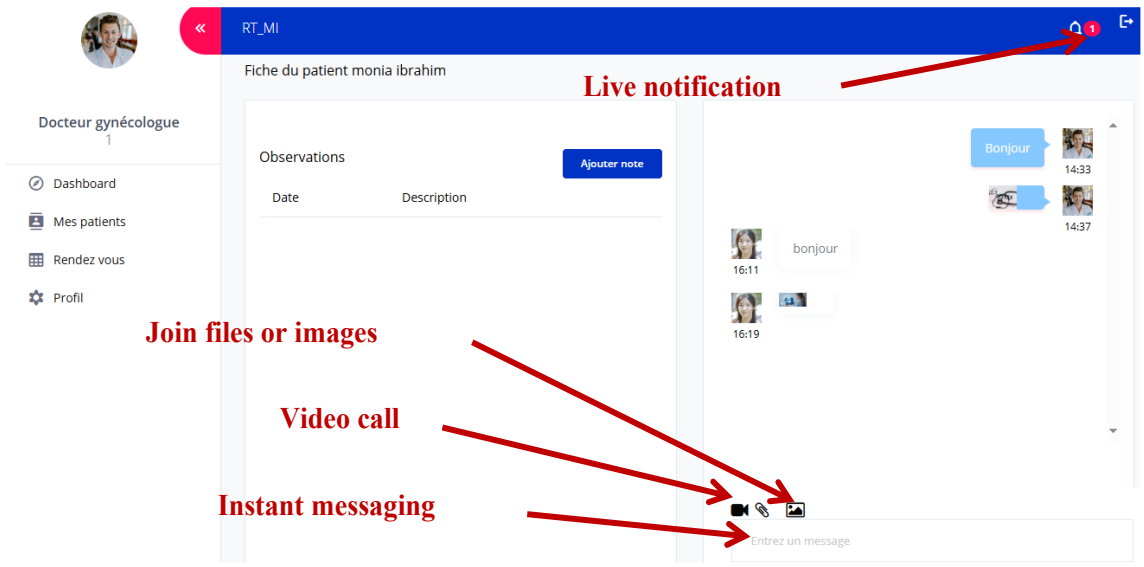

Figure 2. Doctor-patient interaction interface

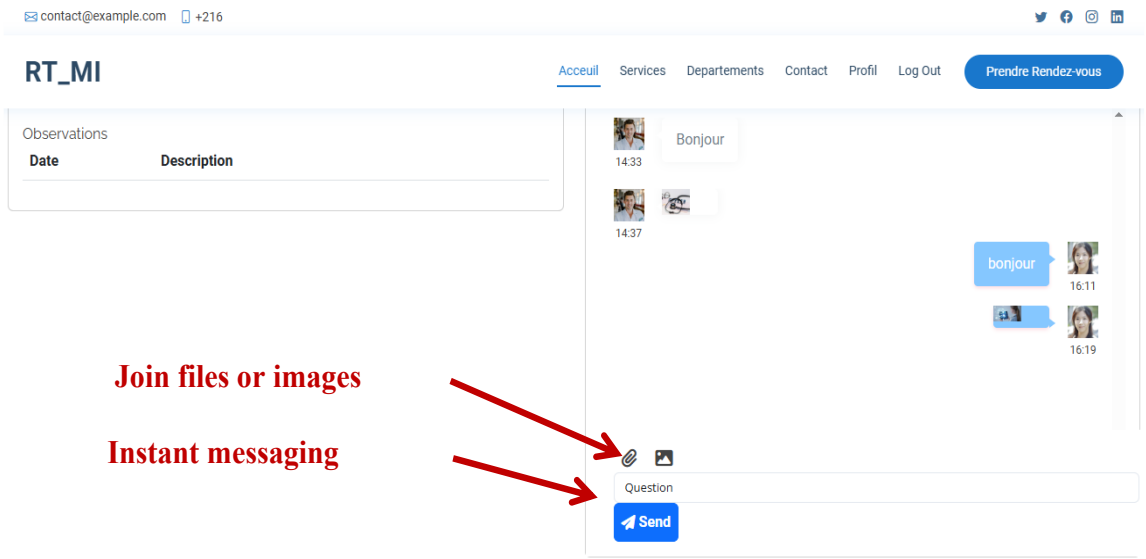

Figure 3. Patient-doctor interaction interface

4. RESULTS AND DISCUSSION

The proposed platform presents such services: real-time Video, instant messaging, live notifications and EHR access. In addition to that among its features and functions: are appointment scheduling and file sharing. The platform allows for the sharing of medical images, test results, and other relevant documents between healthcare providers and patients and secure messaging. Healthcare providers and patients can communicate securely through the platform, ensuring privacy and confidentiality.

This proposed system overcomes the various obstacles faced by patients in rural areas, such as the lack of specialist doctors, the distance to healthcare and the time spent accessing it, which can present a risk to their lives, especially for those with chronic illnesses; therefore, a high-speed internet connection is required to benefit from the platform's services. For each checking visit, the patient must access the platform with authentication, and a doctor will do the requested medical needs. Our platform contains an emergency service, which is a real-time service with health specialists, such as chat via instant messaging as shown in Figure 2 and video call on behalf of the doctor.

We focused on services that ensure patient comfort and satisfaction, which are: Instant messaging, live notifications, electronic prescription and video consultation. Table 1 summarizes a comparison between existing platforms and our one, RT_MI, in providing these services. Our platform offers more telemedicine services in comparison with the mentioned platforms' existing. The strengths of our systems compared with existing platforms are real-time interaction between patient and doctor thanks to 5G, ensuring the transfer of data and access at the same time, real-time communications such as video and audio calls, live notifications and instant messaging.

Table 1. The performance of each Tunisian telemedicine platform

Services	Telemedecine.tn	Tobba.tn	DocNet.tn	Med.tn	Wic-doctor	RT_MI
Instant messaging	No	Not precise	No	No	Yes	Yes
Live notification	Not precise	Not precise	Not precise	No	Not precise	Yes
Electronic prescription	Yes	Not precise	Yes	No	Not precise	Yes
Video consultation	Yes	Yes (variable)	Yes	No	Yes	Yes

4.1. Ethical and data considerations

Laravel and Laravel reverb offer technical tools that help comply with certain general data protection regulation (GDPR) and health insurance portability and accountability (HIPAA) standards. For data security, Laravel offers encryption mechanisms; it uses Bcrypt or Argon2 via (Hash: make ()) to securely store passwords. Also, protection against common attacks via XSS (cross site scripting), cross-site request forgery (CSRF), SQL injection for input data validation, the robust validation system prevents SQL injection or malformed data by filtering server-side inputs.). Laravel allows access management via Middlewares auth, and can, which limits access to medical data to authorized users only, thus ensuring

authentication and authorization. In addition, Laravel allows logging, which allows tracking actions, which is useful for traceability required by GDPR/HIPAA. It also allows secure storage management with the possibility of integration with AWS compliant solutions with encryption and secure servers for infrastructure security: it allows automatic data encryption (at rest & in transit), S3, RDS and other AWS services offer automatic AES-256 encryption, ensuring data confidentiality. In addition, there is a firewall, network security and continuous monitoring with security groups, virtual private cloud (VPC), AWS web application firewall (AWS WAF) and CloudTrail, to be able to block attacks, monitor logs and audit access.

4.2. Future directions and challenges

We are looking to introduce internet of things (IoT) devices interconnected through a network to the platform, using smart sensors that collect and transmit healthcare data in real time. It enables continuous monitoring of patients' vital signs. These devices enable remote patient monitoring and support the early detection of health issues. IoT devices facilitate the integration of various healthcare systems enabling seamless data exchange and interoperability.

5. CONCLUSION

The objective of this paper is to present the design and implementation of such a platform, highlighting its architecture and demonstrating its effectiveness in facilitating remote consultation. In the realization of our platform, we tried to provide all the following objectives: For patients: to provide an appropriate response from the outset of care, and above all with rapid turnaround times, to eliminate inappropriate or unjustified transport to the referral facility (reducing anxiety for patients), to enable patients to remain at home or within medical-social structures, to improve comfort for patients (and their families). For healthcare professionals: improved coordination and continuity of care, notably by facilitating recourse to second-line specialist advice; the possibility of acquiring new knowledge and strengthening inter-professional collaboration; optimization of medical and paramedical time. For public authorities: optimize regional healthcare planning by mobilizing human resources, including in remote areas; maintain a healthcare offer in all regions, which is a factor in maintaining the region's attractiveness; limit healthcare expenditure by preventing complications for patients suffering from chronic illnesses, avoiding or shortening hospital stays, and limiting logistical costs such as transferring patients by ambulance. In the future work we will try to introduce IoT devices interconnected through a network to the platform, using smart sensors that collect and transmit healthcare data in real time to provide more advanced services for patients with greater comfort for them.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

No conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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