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Blockchain-based Decentralized Application for Telesurgery in Metaverse Environment

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***Abstract*—With the advent of technology in the medical industry, telesurgery has emerged as a transformative era of conventional medical practices to facilitate remote and efficient surgical procedures for the betterment of patients' health. Moreover, innovative technologies introduce a full-immersive metaverse environment for enabling communication between patients and doctors virtually and efficiently. Nevertheless, remote telesurgery operations in the metaverse are susceptible to various security and privacy issues that need to be tackled to secure the patient's confidential health data. Thus, we design an Ethereum blockchain-based decentralized application (DApp) for selecting and conducting telesurgery operations based on the doctors' specialization and type of surgery. The proposed application ensures secure and preserved communication between patient and doctor in the metaverse environment by deploying the smart contract in the Remix Integrated Development Environment (IDE). DApp is designed using web3 and JavaScript (JS) to reflect the telesurgery operations to the doctor and patient in the metaverse environment. Finally, the proposed smart contract for the application is evaluated based on parameters such as gas consumption analysis for smart contract functions and doctors registered and cost analysis for smart contract functions.**

***Index Terms*—Blockchain, DApp, Metaverse, Remix IDE, Telesurgery.**

I. Introduction

In the realm of healthcare, traditional practices have been the cornerstone of medical practices, providing the basic and fundamentals for healthcare. These traditional methods or practices involve the patient physically going to the doctor for any kind diagnosis, treatment or management of various health conditions. Yet, these conventional approaches have some limitations owing to the lack of advanced and innovative technology during the patient's treatment. The patient has to physically go to the doctor which makes it a very time consuming process. Moreover, in critical conditions when the patient is suffering from any illness or has to get treated very urgently, it becomes difficult for them to reach the doctor on time. Either they reach on time or they become late in reaching there. Furthermore, they can be contaminated by the communicable diseases during the in-person visit to the doctor [1].

With the advancement and transformation of technology, traditional practices slowly started getting out the league with the advent of the smart healthcare services which started reforming the way healthcare was taken into consideration. These services came into the limelight with the advent of telemedicine which was established as a way to overcome geographical barriers, to improve accessibility and to enhance the efficiency of healthcare delivery. Then, telemedicine era evolved into the telesurgery which facilitates advanced healthcare practices and treatment for betterment of patient. This method involved a doctor performing a surgery on a patient through the medium of a robotic hand that performs the surgery on the patient. Telesurgery includes the doctor, the patient, and the robotic arm that performs the surgery in a metaverse environment where the communication takes place efficiently to meticulously improve the efficiency of treatment and also to solve the issues of time consumption and avoid other patients and the doctors from catching the communicable diseases. The metaverse environment with the convergence of Augment Reality (AR), Quantum Computing, and Virtual Reality (VR) provides a fully immersive environment between patient and healthcare professional for performing remote procedures [2].

Nowadays, the data of the patients gets leaked and comes into wrong hands. These people then manipulate the data in their own way to get their work done. For example, the data of a patient contains information that the patient has a high level of diabetes. But these people change it to low level. Now this creates problem in taking further decision as that change can affect the patient at a very high level and can have adverse effects on them. To resolve the data security challenges in the telesurgery operations, many researchers have considered immutable and decentralized characteristics of the blockchain to treat patient using telesurgery. For instance, Gupta *et. al.* [3] proposed HaBiTs, a blockchain-based framework that helps to mitigate the issues of security, privacy and interoperability using smart contract. They have come up with a very efficient blockchain-based framework towards telesurgery but have not mentioned about decentralized approach. Furthermore, Gupta *et. al.* [4] presented an intelligent telesurgery (TS) system with 6G-enabled Tactile Internet (TI) and have proposed an approach named BITS that is an intelligent and blockchain-based TS framework. But the approach with integrating these technologies poses technical challenges and requires great expertise towards the field.

Then the authors of [5] designed a real-time smart contract-based TS for healthcare 4.0. Nevertheless, blockchain suffers from scalability issues which is not discussed by the researchers to that extent. Considering the aspect of reliability and availability issues in the blockchain network, the authors in [6] proposed a TS that ensures both, ultra-low latency and ultra-high reliability in the communication using 5G communication network. However, their proposed system fails towards managing the cost that incurs from the implementation of this proposal. Despite introducing security and privacy during the telesurgery operations using blockchain, none of the authors designed a decentralized application (DApp) to conduct telesurgery on the patients using robotic arm. Therefore, we propose and design a DApp for telesurgery operations in the metaverse environment that allows efficient communication between the doctor, the patient, and the robotic arm.

A. *Research Contributions*

Following are the research contributions of this paper.

- We propose a DApp for selecting and performing telesurgery operations in the metaverse environment.
- The proposed application shows the communication between patient and doctor so that patient select surgery considering the doctor's specializations and years of experience.
- We deploy the smart contract of the proposed application in the Remix Integrated Development Environment (IDE) and the smart contract code is further connected to javascript (JS) based front-end application through Web3 and EtherJS. Thus creating a decentralised application for reflecting telesurgery operations in metaverse efficiently.

B. *Organization of the Paper*

The rest of the paper is organized as follows. Section II describes the related works. Section III presents the system model and problem formulation of the proposed application and Section IV elaborates the proposed application in detail. Then, Section V presents the performance evaluation of the proposed application. Finally, the paper is concluded with future work in Section VI.

II. Related Works

Various authors have used telesurgery and blockchain to ensure immutability and interoperability from any location safely for patient efficient and secure treatment. The authors in [5] designed a system (AaYush) that utilizes ESC (Ethereum smart contract) and IPFS-based TS system to resolve security and privacy issues and storage cost issues, respectively. Alongside, it puts forth a real-time smart contract written in solidity enacted in Truffle suite. Further, researchers in [7] proposed BATS, a 6G telesurgery system empowered by AI and blockchain, ensuring ultra-reliable and low-latency communication. It employs an AI algorithm to classify disease criticality and UAVs to transport healthcare items. The main issues in the proposed work are that they have to rely highly on the UAVs that they have proposed for transportation of light-weight healthcare items and that they may face trust and transparency challenges. So, to provide proper execution of the proposed system, there was a need for a platform that everyone can access and use telesurgery systems easily.

In the recent past, various researchers have presented frameworks that have implemented healthcare in the metaverse, which provides a safer, more efficient, better virtual care and less costly alternative to physical medical visits and operations. For instance, Bhattacharya *et al.* [8] presented a blockchain and explainable AI-based system which is significant in fostering transparency, immutability, and trust in metaverse-based healthcare 5.0., as they work together to improve clinical decision support and enables innovative telesurgical schemes. Further, Dilibal *et al.* [9] proposed the implementation of embedded Esantem smart healthcare in the metaverse. It examines adjustments of traditional healthcare in the metaverse, improving human-computer interaction and securing the handling of wearable biomedical device medical data. Later, Mozumder *et al.* [10] introduced an explainable AI , blockchain, and immersive technology based framework for metaverse healthcare, and it has the potential to enhance patient outcomes and transform the healthcare industry.

The above-mentioned systems have various de-merits, as many systems use only blockchain and smart contract approaches or only telesurgery with advanced communication technologies. Some systems have also implemented telesurgery using metaverse, but there is no framework where blockchain, telesurgery, and metaverse have been combined to provide a better and safer solution. Moreover, they have not designed a DApp in which patient and doctor communication reflects further showing the remote procedures using telesurgery. Thus, we design a DApp (utilizing web3 and JS)) in which a smart contract is implemented using Remix IDE, which carries out transactions between metaverse, patients, and doctors. The admin validates the doctors participating on the platform and their data. The patients can choose the doctor for getting their telesurgery operation done based on doctor ratings in the particular speciality. The doctors can also reject or accept a surgery based on the time slot selected by the patient and their past medical history. The complete process is monitored by the admin, who keeps track of the telesurgery in the metaverse.

III. System Model and Problem Formulation

A. *System Model*

The proposed application comprises a patient α and a doctor β who are involved in the whole telesurgery (σ) process with a robotic arm Υ which operates the patient in place of the doctor and this system which includes the doctor, the patient, admin, and the robotic arm is termed as metaverse environment (μ). The patient makes a request ε for surgery after undergoing a health check-up, which is done by collecting data based on various factors using their respective equipment and coming out as fit for the surgery without any disease being diagnosed that can hopefully be dangerous during the surgery. After the patient requests for surgery, the patient has to enter the speciality and type of surgery ($\mathcal{S}$). The patient is required to undergo surgery and has to select the corresponding doctor that would perform telesurgery on them. Here, the doctor's information is also provided, which includes specialization(γ), experience (δ), reviews (ϵ), etc. These measures help the patient in judiciously choosing which doctor best fits for the surgery and can do their best in it. After this procedure, the robotic arm performs surgery on the patient with the help of a doctor who remotely operates it.

After the surgery is completed, the patient fills out a form wherein they have to rate or give feedback to the doctor. Based on the surgery the doctor performs, the patient gives feedback (ζ) to the doctor. The doctor, after the completion of the surgery, has to end the surgery, which reflects on the platform; only after which the doctor can accept a new surgery at the particular time. The feedback can be given by the patient only after the doctor has ended the surgery. The medical data of the patient might get into the wrong hands, which can be very dangerous for the patient. The attackers might manipulate the data to get their work done. For this purpose, we design an Ethereum blockchain-based DApp in which a smart contract for the proposed system is implemented in the Remix IDE and connected through web3 using JS to build the entire application for telesurgery operations. Further, we consider the Interplanetary File System (IPFS) protocol (π) to ensure cost-efficient storage of the data that could have been a problem if it would have been stored in the form of data blocks. The IPFS protocol provides hash keys (ν) that can be further provided to blockchain technology which produces public key (θ) and private key (ϑ), which help for an easy and secure access to the data.

B. Problem Formulation

Before the telesurgery (σ) takes place, healthy communication takes place between the patient α and the doctor β where the doctor checks on some of the factors that can become a hindrance during the telesurgery. The patient is also checked for other factors like diabetes, blood pressure, hypertension, etc., to ensure a successful telesurgery at the place where the telesurgery operation is going to be held. So, the communication between patient and doctor for telesurgery is represented as follows:

$$\alpha \xrightarrow{communication} \beta \tag{1}$$

Then, the patient makes a request (ε) to the doctor for carrying on with telesurgery using the robotic arm (Υ). There are several options of surgery types in a particular speciality ($\mathcal{S}$) from which the patient chooses and based on that doctors with different specializations are available for treatment purpose. The list of surgeries contain their corresponding doctors whose information like specialization(γ), experience, feedback (ϵ), etc. is also provided so that it makes easy for the patient to choose the best suited doctor for that particular surgery. Thus, information about the surgery and the doctor with the specialization is mentioned as follows:

$$\mathcal{S} = \{\mathcal{S}_1, \mathcal{S}_2, \mathcal{S}_3, \mathcal{S}_4, \dots\} \tag{2}$$

$$\beta = \{\beta_1, \beta_2, \beta_3, \beta_4, \dots\} \tag{3}$$

$$\mathcal{S}_i \rightarrow \beta_i\{\gamma, \epsilon\} \tag{4}$$

where:

- $\mathcal{S}_i$ = i^{th} surgery type
- β_i = corresponding i^{th} doctor with information

The telesurgery is performed between patient, the doctor, admin, and the robotic arm is collectively known as the metaverse environment (μ). These processes mentioned above take place in this environment where effective communication is the key for an efficient surgery. Eq. 5 shows the patient making a request to the doctor for the selected surgery in the metaverse environment.

$$\{\alpha\{\mathcal{S}\} \xrightarrow{\varepsilon} \beta\}^{\mu} \tag{5}$$

After the request is granted, the procedure is taken further and the surgery is performed on the patient. The doctor perform surgery on the patient through the robotic arm in the metaverse environment. Once the surgery is completed, the patient is supposed to provide feedback (ζ) based upon the surgery performed by the doctor. The rating to the doctor can be between 1 to 5.

For the proposed application, we have created the rate doctor function (O_b) that aims at optimising the positive feedback of the doctors which is mentioned in Eq. 6.

$$O_b = \begin{cases} \alpha \xrightarrow{\xi} \text{opt}\{\beta(\mathcal{S})\} \\ \alpha \xrightarrow{\xi'} \beta(\mathcal{S}) \end{cases} \tag{6}$$

Based on the objective function, the patient provides feedback to the doctor. The feedback generally depends on the way the surgery is performed and the output of the surgery. If the surgery is successful, the patient provides a positive feedback generally between 4 or 5 (η) which increases the average feedback points for the doctor and if the surgery is unsuccessful, the patient provides a negative feedback that is 1 or 2 (λ) which decreases the overall average feedback points of the doctor.

$$\xi : \alpha \xrightarrow{\eta} \beta\{\mathcal{S}\} \tag{7}$$

$$\xi' : \alpha \xrightarrow{\lambda} \beta\{\mathcal{S}\} \tag{8}$$

With the advent of technology, many unfair practices have also been at a rise. The patient's confidential data may get leaked during communicating with the doctor in the metaverse environment. They may change the records according to their will in order to get their favor done. To avoid this leakage of the data and to securely store the data, we design a Ethereum blockchain-based DApp in which patient select the type of surgery based on the doctor's information and their specialization through IPFS. The data is securely stored using the IPFS protocol (π) and is easily accessed using the public (θ) and private (ϑ) keys.

IV. The Proposed Application

In this section, we elaborate the blockchain-based DApp to select the surgery and perform telesurgery operations in the metaverse.

A. Home Page

The home page (τ) is the primary page for the designed DApp as shown in Fig. 1. The doctors and patients accessing the DApp are firstly required to register themselves through this page. The doctor registration is required to verify doctors accessing the telesurgery metaverse platform in order to provide safety and transparency to its users. Thus, registration for patient and doctor through the home page is mentioned as follows:

$$\tau \xrightarrow{register} \alpha, \beta \tag{9}$$

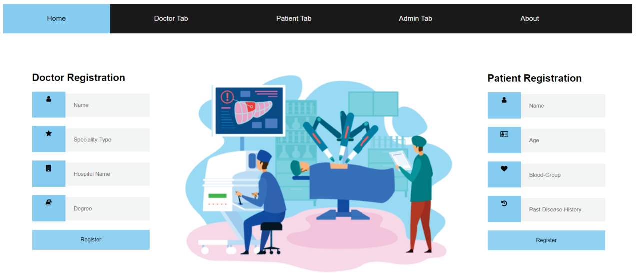

Fig. 1: Home Page.

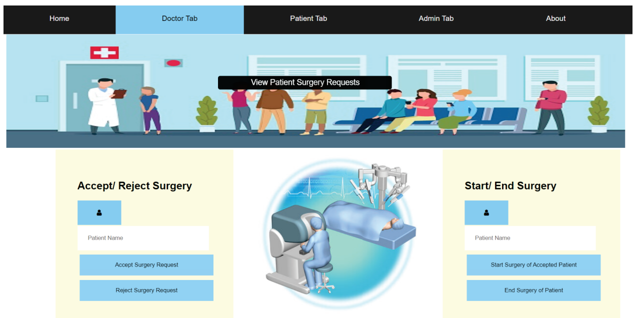

Fig. 2: Doctor Page.

Doctors register themselves by entering their name, speciality type they have mastered, hospital in which they are currently affiliated to, their medical degree, along with years of experience in the same field. These date is added to blockchain and hence, is transparent and immutable. Patients are required to register themselves in order to further access telesurgery DApp. Patients register by entering their name, age, past medical history (δ), and blood group. Eq. 9 represents the registration of patient (α) and doctor (β) on the home page (τ). These date further helps the doctors in making rightful decisions regarding surgery request of the patients.

B. Doctor Page

Fig. 2 depicts the doctor's page (β_1), which is to be used by doctors after the registration is completed on home page. Here, the doctor gets to view patient requests, which appears when a particular patient approaches the doctor for selecting surgery through them. The doctor gets to view patient name, and timing requested for surgery performed by them. After viewing the patient requests, the doctor has to accept the surgery request or reject it, by entering the patient name in the provided tab as represented in Eq. 10.

$$\beta_1(\alpha) = \begin{cases} Accept \text{ if } \psi = \text{avail}, \alpha \\ Reject \text{ if } \psi = \text{Occupied} \end{cases} \tag{10}$$

$$\beta_1(\alpha, \psi) \rightarrow \text{Start surgery} \tag{11}$$

$$\beta_1(\delta) \xrightarrow{EndSurgery} \epsilon avail \tag{12}$$

Once the surgery request has been accepted, the telesurgery is performed by entering the patient name on the start surgery tab when the selected time slot (ψ) is achieved as shown in Eq. 11 and history α of the patient is good. This data helps to keep record of the duration of operation on metaverse.

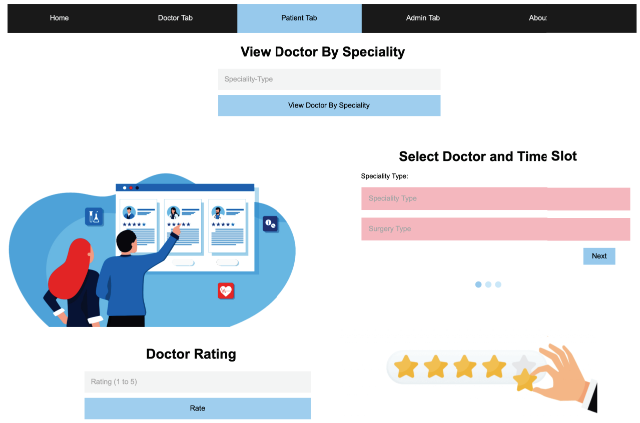

Fig. 3: Patient Page.

Telesurgery is further performed by the doctor at his operating site and patient is present at another respective location from where they have approached for telesurgery. At last, once the operation is completed the doctor has to end the surgery from end surgery tab, which reflects in the doctors data of operated patients. After the surgery is ended by doctor, the patient is privileged to provide feedback (ϵ) for the same as shown in Eq. 12.

C. Patient Page

The patient page (α_1) as shown in Fig. 3 is to be accessed by patients who are willing to take part in telesurgery and have registered themselves through the home tab. The patients can view doctors using the platform by entering the speciality type (π). A list of doctors performing surgery under that speciality is printed along with their rating. The patients can further select the speciality type (π), surgery type (ρ), time slot (ψ), and enter doctors name (β); through whom they want to get their surgery performed as represented in Eq. 13. Once, this request has been made by the patient, the same appears on requests list of the particular doctor.

$$\alpha 1(\beta, \pi, \rho, \psi) \xrightarrow{RequestSurgery} Submit \tag{13}$$

Once, the surgery has been accepted and completed; the patient can give ratings to the doctor based on their experience. If the doctor rejects the surgery request of the patient, they approach some other doctor. However, if the request is accepted, the same is reflected on the patient's tab.

D. Admin Page

The admin page (ν) as shown in Fig. 4, works as the main authorization and monitoring page for the metaverse platform. The admin has the authority to add surgery, and authorise the doctor as mentioned in Eq. 14 and 15. The authorize doctor (χ) function can be used by entering the doctor name to authorize them for the telesurgery operations that need to be performed on the patient. This is to be done once the doctor has registered to take part in telesurgery. Once, the admin authorizes the doctor, they perform further functions in the DApp for conducting remote procedures on the patient in the metaverse environment.

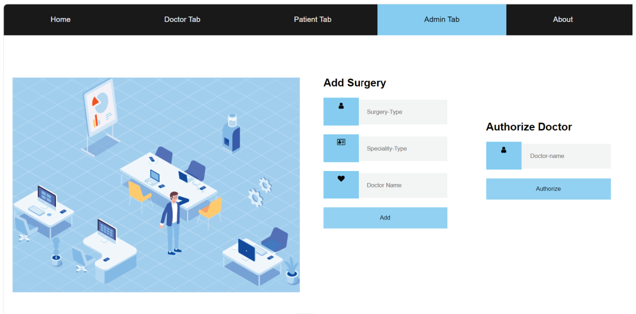

Fig. 4: Admin Page.

$$\nu(\beta, \pi, \rho) \xrightarrow{AddSurgery} SurgeryAdded \tag{14}$$

$$\chi(\beta) \rightarrow Authorized \tag{15}$$

Algorithm 1 Algorithm for telesurgery using DApp.

Input: α, β
Output: Telesurgery with feedback

procedure TELESURGERY(S, γ, δ, π, ρ, ψ)
  $HomeTab \xrightarrow{register} \alpha, \beta$
  View Doctors in speciality type, π
  Request Surgery from Selected Doctor
  $PatientTab(\beta, \pi, \rho, \psi) \xrightarrow{RequestSurgery} Reflectedin\beta 1$
  if $\psi == Empty \& \delta == Satisfactory$ **then**
    Accept Surgery Request
    if $\psi == Arrived$ **then**
      $\beta \xrightarrow{Start} \sigma$
    else if $S = completed$ **then**
      $\beta \xrightarrow{End} \sigma$
      $\alpha \xrightarrow{DoctorRating} \varnothing_b$
    end if
  else
    Reject Surgery Request
  end if
  Authorization by Admin
  $\beta \rightarrow Authorize$
  $S(\pi, \rho, \beta) \rightarrow Authorize$
end procedure

Algorithm 1 states the basic process of the proposed decentralised application. Firstly, the patients and doctors need to register on the home page by entering their required details. After that, the patients can view the available doctors for a particular specialization with their rating. Through the list, the patient selects the doctor for their telesurgery operation by entering their speciality type, surgery type, and doctor name. After that, the surgery request has been made and the same is reflected on the doctors page under the requested surgery function. The doctor accepts the surgery if the selected time by patient is suitable and their medical history is satisfactory for the operation.

Once, the surgery has been accepted the doctor can start the surgery at the proposed time and once it is completed the doctor can end surgery to store the data related to surgery time and other information. The patients can rate the doctor based on a scale of one to five, five being the highest rated based on their telesurgery experience. Moreover, if the doctor is busy in the selected time slot they need to reject the surgery. Additionally, the admin has to authorise the doctors who have registered after verifying their data to perform telesurgery on the metaverse platform. The admin also needs to add various specializations with the surgery types available for the patients as a option.

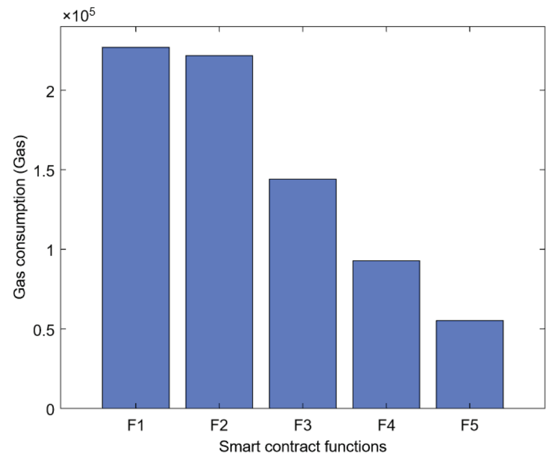

Fig. 5: Gas consumption analysis for smart contract functions.

V. Performance Evaluation

In this section, we discuss the performance evaluation of the proposed DApp to facilitate patient selection of telesurgery from the available doctors associated with the specializations. The proposed DApp is designed with the help of web3, JS, and Remix IDE. We have considered various parameters such as gas consumption analysis for smart contract functions and doctors registered, and cost analysis for smart contract function.

A. Gas Consumption Analysis for Smart Contract

Fig. 5 depicts the gas consumption analysis of various smart contract functions used in the proposed application that helps in the telesurgery process on metaverse and facilitates communication between patients and doctors. The function F1 represents the *RegisterDoctor* function, which is available on the home page of the DApp. Doctors can use this function to register themselves for telesurgery operations on metaverse. To register, the doctors need to enter their name, degree, specialization field and the hospital they are affiliated with. Similarly, the function F2 depicts the *RegisterPatient* function, which can be used by patients willing to undergo telesurgery to register. They need to enter their name, age, past medical history, if any, and blood group. The function F3 shows the *AddSurgery* function, which is present in the admin tab, where the admin can add surgery by entering the surgery type and specialization along with the doctor with the authority to perform the same. Further, function F4 represents the *SelectDoctor* function, which is present in the patient tab. The patients can select the doctor by entering the surgery type, specialization, and entering the doctor's name. The selection can be done after reviewing the doctor's list under a particular specialization. Lastly, the function F5 shows the *TimeSlot* function, which is also present to facilitate the patients in the telesurgery process by letting them select the desired time for their telesurgery operation. The time slot can be morning, afternoon, or evening. This function requires the least gas consumption as the time slot with its designated number (i.e.,

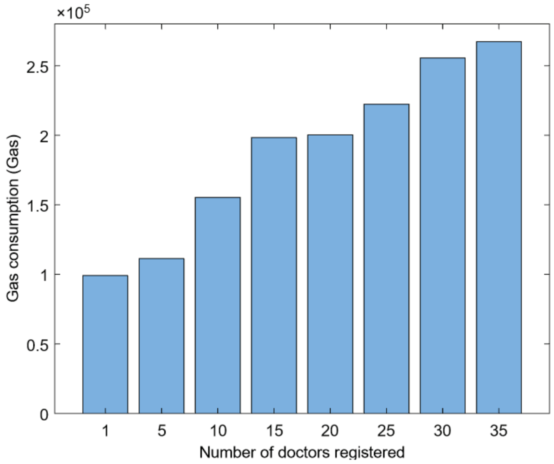

Fig. 6: Gas consumption analysis for doctors registered.

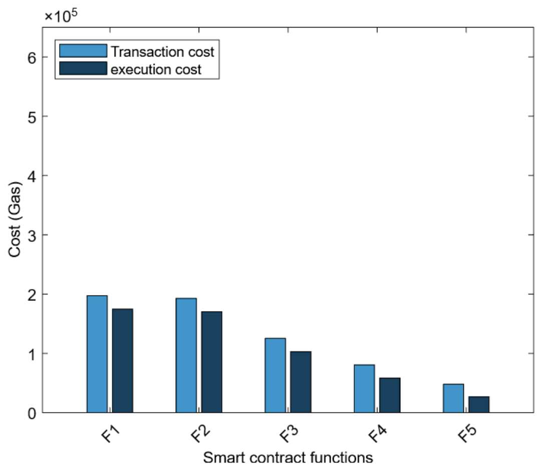

Fig. 7: Cost analysis for smart contract functions.

0,1,2) can only be saved.

Fig. 6 represents the gas consumption analysis of the registration of various numbers of doctors. As the number of doctors increases, the gas required for their registration increases, which is depicted from the graph. The first bar shows the gas consumed in registration of one doctor and the last bar shows the gas required to register 35 doctors.

B. Transactions and Execution Cost for Smart Contract

Fig. 7 shows the cost analysis of the above described smart contract function. The graph shows the transaction and execution cost of the five functions stated above. The function F1 *RegisterDoctor* requires the highest transaction and execution cost as the function requires many sub-fields and information about the doctors to be saved. The function F5 represents the *TimeSlot* function which requires the least transaction and execution cost as only the data related to selected slot is to be saved for the patient. All the other functions require higher costs as they have more than one fields to be entered and detailed data to be saved for patients and doctors.

VI. Conclusion

In this paper, we design a blockchain and telesurgery-based DApp to make surgery available to patients in the metaverse environment. The proposed application involves patient requesting surgery through their information, such as name, timeslot, and medical history. Further, doctors along with their information such as speciality, years of experience, and name, help patients to select the doctor for telesurgery purpose. The proposed application also facilitates feedback to the patient about the surgery performed in the metaverse environment. Moreover, we have executed the smart contract of the proposed telesurgery scenarios in the Remix IDE and connected it through web3 using JS to reflect various functionalities for telesurgery. Finally, we have evaluated the proposed application with the help of deployed smart contract in terms of gas consumption analysis for smart contract functions and doctors registered and cost analysis for smart contract functions. Further, in the future we will include a billing system for patients in the DApp based on the under-gone surgery, doctor selected, any other factors. Also, plan to implement an optimization mechanism to optimize the telesurgery operations, for the patient in the metaverse environment by letting doctors select their required tools and procedure through the DApp.

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