SECURING DIGITIZED CAMPUS CLINICAL HEALTHCARE DELIVERY SYSTEM

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Abstract: Tele-ClinicalDiagnostic System (TCDS) isa robust care delivery system with the capability to enhance healthcare services at remote locations. Characteristically, TCDS can be articulated to improve efficiency, trust, cost effectiveness and enhancepractitioners work productivity. In this paper, we present the design, development and qualitative performance evaluation of a Secure Tele-Clinical Diagnostic system for geographically dispersed academic environment in developing country like Nigeria. The system was developed using synergistic application of Advanced Encryption Standard cryptographic technique for medical data confidentiality, Web Real Time communication for clinical Tele-consultation and simplified multi-tier electronic health system. The developed system was evaluated in Federal University of Technology Minna, Healthcare Service Centre using expert's perceptive qualitative performance evaluation method. The results of the evaluation revealed that the developed system is efficient and effective in delivery of secure clinical healthcare in geographically dispersed tertiary institution healthcare centers and similar institutions in sub-Saharan Africa.

Keyword: E-health,Telemedicine, Confidentiality, Privacy, Real-time,Tele-consultation.

INTRODUCTION

The application of Information and Communication Technology (ICT) in different facets of life has become increasingly important in many countries in recent years including healthcare. Over International and national standardization for interoperability and data exchange, there has been continuing progressive efforts. Many different applications have been developed for electronic healthcare (like e-health recording) inRau *et al.* (2010), accounting and billing in Sosian, (2006), medical research and intellectual property in Hsu & Pan (2013) and Tele-consultation with e-health record in Emuoyibofarhe *et al.*, (2014). Particularly, e-health systems like Electronic Health Records (EHRs) decrease the costs of healthcare through avoidance of expensive double diagnoses, repetitive drug administration and improved personal healthcare management.

E-health system was introduced to the need of healthcare delivery as a result of inadequate quality facility. E-health system is also a further development of the idea of Telemedicine Barbara *et al.* (2010). It covers the point of interconnection between patients and healthcare service providers, institution located in one place to another, peer to peer communication between patients and health professionals. E-Health, defined inthese categories of activities, although limited studies suggest an alternative means to improve access and quality of care Lawal (2013). E-health applications include Telemedicine and Electronic Health Recording (EHR).Telemedicine isthe application ofInformation and Communication Technologies for the delivery of health care services, where distance is a critical factor, for the exchange of valid information, diagnosis, treatment and prevention of disease and injuries, research as well as for the continuing education of health care provider in the interest of advancing the health of individuals and their communitiesHo & Cordeiro (2010).

In view of transforming rural settlements to urban settlements, tertiary institutions in developing countries practiced multi-campus academic systems. This developmental agenda brings economic, social and infrastructural privileges to host rural settlements. However, there is tendency for duplication of scarce infrastructures and human capital resources on the part of these multi campus tertiary institutions. One of these possible scenarios is the provision of medication to students, staffs and host communities. Medical experts in most developing countries are still scarce human capacity and application of ICT to medical healthcare delivery through telemedicine could assists to reduce this duplication of this scarce resource in geographically dispersed academic environment.

EHRon the other hand is a type of application that is relatively new to the care delivery system, and definitions of their functionality are constantly evolving as knowledge of an experience with these tools increase. Nonetheless, such applications typically provide access to patient-oriented views of the health care professional's EHR with selected views of health information retrieved from multiple sources. These consumer-oriented applications may also support the ability for patients to contact their health care professional's office or clinic via secure e-mail for administrative or non-medical reasons, and provide links to vetted health information sources Rudolph *et al.* (2008).

Apparently e-health systems process and store very sensitive data and should have an appropriate privacy framework. The disclosure of health data may have severe social effect on patients. If confidential health data is leaked outside the e-health system, accidentally or deliberately, the responsible health professionals or IT providers would have to face severe legal penalties for violating privacy laws. The problem of e-Health include: authorization, authentication and accounting as common to other Information Technology applications such as banking and manufacturing Brewer, (2011). E-Health involves information security and privacy as well as physical safety.

The security requirements of e-health systems, technically speaking, are not particularly different from those required in other information technology application domain. The security function is based on available of proper mechanism and algorithms of authentication (identification and verification), identity management, confidentiality, integrity as well as availability and accountability. In this paper, data security attribute of Advance Encryption Standard cryptographic algorithm was combined with remote real time communication of Web Real Time Communication framework to provide secure, remote and real time clinical diagnosis for medical experts in geographically dispersed academic environment.

The remaining section of the paper is organized into four sections: Section II provides the review of related work; the system design methodology is presented in section III; Results and Discussions were presented in section IV, Section Vconcludes and provides scope for future research endeavor.

LITERATURE REVIEW

A number of related works exists in the application for ICT for provision of medical data privacy, convenience and diagnosis, treatment and prevention of diseases at near and remote distance in literature. Hans and Ahmad-Rezain Hans *et al* 2010proposed securing the e-health cloud by presenting security architecture for establishing privacy domains in e-health infrastructures. This proposed system provides solution for client platform security. The work proposed building privacy domains for patients' medical data as a technical metric to enhance the enforcement of data protection and privacy policies. The proposed system is limited to medical data recording unit and did not provide security for server back end.

Also, authors in Joseph *et al*., (2003) developed computer oriented patient record system in sub Saharan Africa to eliminate duplication of medical files and data recorded in paper form. The system was developed with Microsoft office access database and is maintained by severance power system. The outline of clinics visited, tests perform, diagnosis made and drug prescribed were presented. When a new patient is enrolled into the electronic medical record system, a plastic tag is issued that carries the patient name and electronic media record system number. The assigned tag was used by patient for medical consultation with medical practitioners. This system proposed could only operate in one recording unit and it is not secure, therefore the developed system was inefficient.

A robust clinical information tool for electronic medical recordwas developed by authors inBarbara *et al* (2010). In this work, authors examined that the right to use exact knowledge enhances tendency to respond to medical matter at the point of care as a major element of health care excellence. The developed system provides meta-search for the clinical answers including check-up, training of patient and treatment drug information. The study of information manager reveals that more than half of the question of clinician could be solved. The system is not efficient as a result of its inability to cover more than one unit of the health centre as well as lack of provision of privacy security measure for patient data. Similar medical smart card system for patient record management was developed by Changrui & Arthur (2009) .The developed system could only automate medical health record and did not provide design consideration for medical data security and remote consultation.

In Emuoyibofarhe *et al.,* (2014), the development of a robust tele-consultation with electronic health record integrated with three Nigerian major Local languages of Igbo, Yoruba and Hausa was proposed. Although the developed tele-consultation system was proved to be usable after evaluation and could be effective for effective delivery of medical care at distance in the patient natural language, the developed system lacks design consideration for protection of medical data confidentiality and privacy which are critical in e-health delivery at geographically dispersed sites. Another design limitation was lack of provision of critical unit operations like pre-clinical and laboratory investigations as well as post-medical drug dispensing by pharmacists at remote sites.

The development of a functional and well-engineered e-health system for comprehensive automation of clinical healthcare delivery of five operational units of Federal University of Technology Minna healthcare Services was proposed in Lawal (2013). These operational units are medical consultation, nursing, recording, laboratory and pharmacy. The developed system was further evaluated at the University Health center using expert's perceptive analysis. The developed e-health system lacks design consideration data confidentiality and privacy, billing and remote consultation from scarce medical practitioners in such geographically dispersed academic environment like Federal University of Technology Minna healthcare center.

In this work, we improve on these related works by exploiting the capacity of Information and Communication Technology (ICT) to extend automation beyond medical recording as does in (Hans *et al* 2010; Joseph *et al*., (2003); Barbara *et al*

(2010))and seamlessly apply Real time Communication framework for real time tele-consultations and Advance Encryption Standard of symmetric cryptographic algorithm to provide data confidentiality and software enhancements for billing to extend limitations of Lawal (2013)and Emuoyibofarhe *et al., (*2014).

MATERIALS AND METHODS

In this section, technical solution that satisfies the functional requirements for the system is presented. The functional specification produced during system requirements analysis was transformed into a physical architecture through system modeling and database design. The transformed system was developed using Hypertext Pre -processor run time, Apache, My Structure Query Language and Node JavaScript. Thereafter, the developed system was tested and evaluated against benchmarks by experts.

Requirements Definition for the Secure Tele-clinical Diagnostic System

The requirement definition follows from the premises that the design of secure tele-diagnostic system for remote and near clinical medical delivery should provide:

a) **Convenience**: The system functional components for individual unit of medical facility should be available to experts for seamless accessibility which makes them an ideal tool for performing personal tasks. These tasks should cover operations in medical record unit, nursing unit, physician prescription unit, pharmaceutical dispensing unit, clinical laboratory investigation unit, dentistry unit and billing unit;

b) **Usability**: The secure tele-diagnostic system must be expert friendly with little or no learning curve to the experts. The experts must also be able to personalize the diagnostic system environment to suit his or her convenience. The graphical user interface and tool tips should be provided to guide the experts to perform vital unit operations;

c) **Interoperability:** The design of the secure tele-diagnostic system should be based on standards and open technologies that allow various modules of the system to interact with other systems;

d) **Security, Privacy and Trust**: Patient should able to trust and count on medical expert against breach of their medical data. The system should be designed to keep patient data secret. Accessibility to data should be available to authorized experts and/or user only. A threat to confidentiality is disclosure of information. Therefore, each unit of the medical facility will only have access to patient data that is related to their unit. The system should be foolproof, resistant to attacks from an intruder while communicating medical over public communication channels. The integrity of medical data should be established in the design of the overall system.

Overall System Architecture

The architecture shown in Figure. 1 describes how the system operates using the University Health Service of Federal University of Technology, Minna (FUTMINNA) as the test bed. The system covers eight unit of FUTMINNA healthcare center beginning from medical recording unit, medical consultancy unit, dentist unit, nursing unit, pharmacy unit, laboratory unit, radiology unit and accounting unit integrated as a system for two sites located at Gidan kwano and Bosso campus linked together as a system. The components of the system from Figure. 1 are:

a) Electronic Health Record (EHR) Module: The module archives enrolled electronic record of patient health information provided by patient to medical record keeping. Included in this information are patient demographics, progress notes, problems, medications, vital signs, past medical history, immunizations, laboratory data and radiology reports. EHR module automates and streamlines the clinician's workflow. The module has the ability to generate a complete record of a clinical patient encounter including evidence-based decision support, management and outcomes reporting;

b) Electronic-Prescription Module: This module enhances the productivity of medical physician through electronic transfer of an accurate, error-free and understandable prescription directly to pharmacy and/or laboratory technologist for pre-clinical investigation. The model allows the doctor to prescribe drugs which will be sent to pharmacy via communication network;

c) Electronic-Clinical Laboratory and Radiological Investigation Module: This module allows the laboratory technologists and radiologist to access investigation instructed by doctors available on the network. The result of the investigation by requirements is privately send back to the physician via the same channel of communication;

d) Pre-electronic clinical administration by Nursing Practitioner Module: This module enable nurse(s) to perform pre-clinical data capturing for physician prescription consideration and to have access to the treatment instructed by doctor on specific patient and give feedback electronically; e) Real Time Communication Module: This module facilitates tele-consultation to medical experts through an integration of an API definition drafted by the World Wide Web Consortium for browser-to-browser applications support for voice calling, video chat, and P2P file sharing without the need of either internal or external plugin. The module provides seamless platform for voice and video communication among all units in the secure tele-diagnostics system.

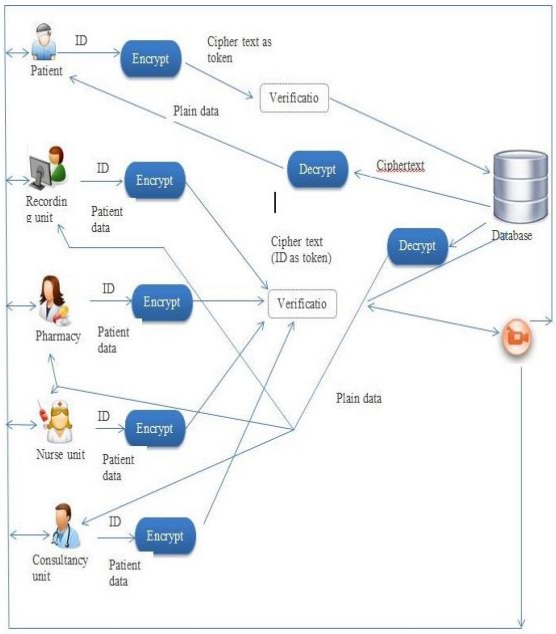

Figure 1: Secure Tele-clinical Diagnostic System Architectural Diagram

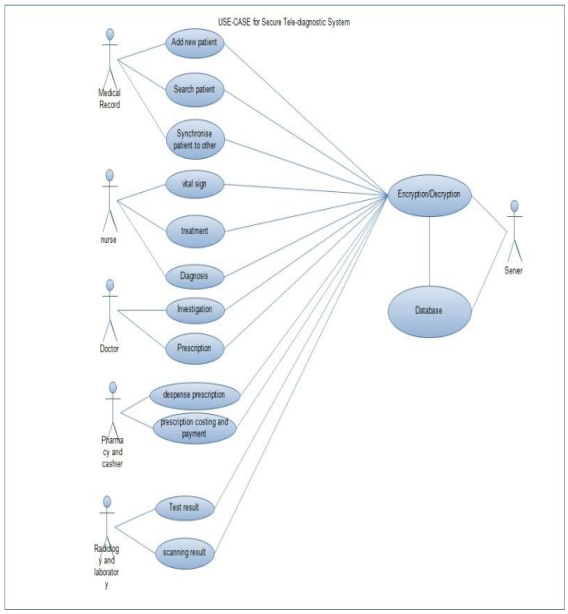

Figure 2: Use Case Diagram of Tele-clinical Diagnostic System

System Modeling

The structure of the proposed system was modelled using the use-case diagram, activity diagram diagrams and the behavioural/sequence diagram using object oriented design paradigm. The use case scenario of the proposed system is shown in Figure. 2.The administrator controls the activities of the system and major functions of the system. The use case diagram of the secure tele-clinical diagnostic system involves five actors: medical record, doctor/dentist, nurse, pharmacy, dentist, radiology/laboratory, and accounting unit. Figure. 3 shows the activity diagram of the system.

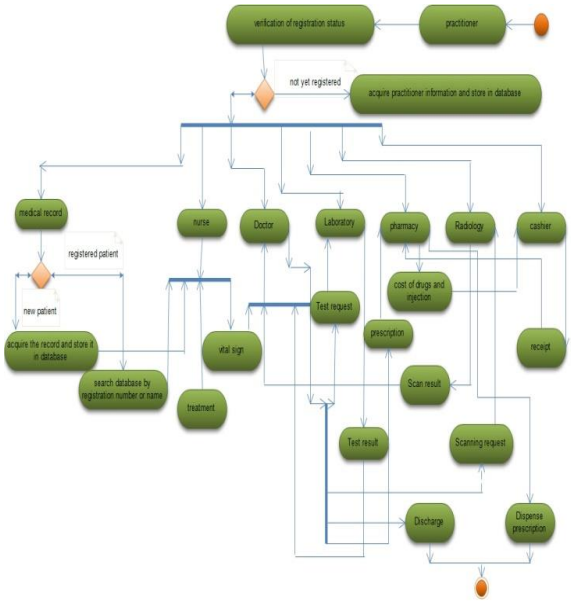

Figure 3: Activity Diagram of Tele-clinical Diagnostic System.

System Security Design Considerations: The security design consideration for the system is based on the principle symmetric cryptography using Advanced Encryption standard (AES) for medical data protection from each unit to the database. AES is a symmetric block cipher. By definition, symmetric algorithms have one key. So both the sender and the receiver need to have the same key. A block cipher is a method of encrypting text in which a cryptographic key and algorithm are applied to a block of data at once as a group rather than to one bit at a time. The specification of the AES block cipher, defines two functions: encryption that generates ciphertext and decryption that produces plaintext. The AES has a block length of 128 bits and key length of 128,192 or 256 bits [7,13].Advance Encryption Standard of 192 bit key length is used because the longer the key used for encryption, the stronger the security strength. The encryption of medical data takes place at the middle tier at the point moving data into database and decryption happen at the point of medial data retrieval. Figure.4 describes the application of this security technique in this system.

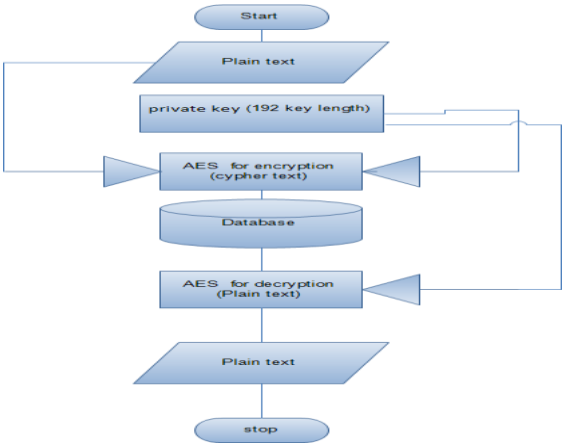

Figure 4 Security design of Secure Tele-clinical Diagnostic System

Database Design

Databases are integrated collection of fields, data element, and records information need of an organization. Unit of data are independently retrievable. The database which contains tables of the eight units of Federal University of Technology Minna healthcare center described in Figure.1is graphically depicted in database design shown in Figure. 5.

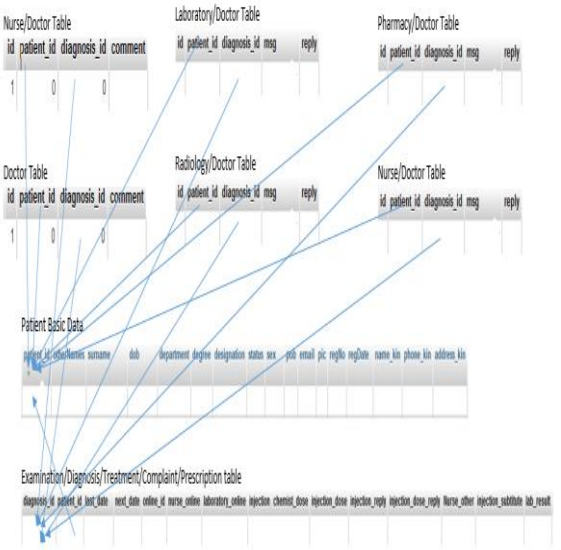

Figure 5: Database design of the Secure Tele-clinical Diagnostic System

System Performance Evaluation

The performance evaluation of the developed secure tele-clinical diagnostic system was carried out through perceptive assessment by medical practitioners (Physicians, Pharmacists, Nurses, Medical Technologists, Medical health record personnel) on the test-bed: FUTMINNA Health Service through administration of well-structured questionnaire during system pilot testing at the Gidan Kwano Campus. The system was rated against earlier defined requirements: usability, efficiency in healthcare delivery, medical data confidentiality, real time communication and accuracy in billing using Likert descriptive non-parametric data analysis in SPSS. The age range of respondents was between 18 years to 65 years. The values/strength and Linguistic labels for the questionnaire designed used for analysing the performance was 5-point Likert items defined as: 5-Strongly Agree, 4-Agree, 3-Undecided, 2-Disagree, 1-Strongly Disagree. The responses of the respondents were measured based on the linguistic strength with worst response (i.e. Strongly Disagree) given to the lowest strength and the best response (Strongly Agree) given to the highest strength. The results and implications of the findings are presented in the next section.

RESULTS AND DISCUSSIONS

Figures 6, 7, 8, and 9 shows the impact of the developed system using ICT could have on secure medical consultations for near and remote patient. The system login page shown in figure 5 welcomes the medical experts to the system. This page allows the expert to fill in the login credentials of password and username, if medical expert is an existing user; else the expert consults the administrator for credentials for using the system. If there is mismatch in the log in credentials of username and password, the system triggers an "***error login error, check your password and username"*** , in this case, the medical experts should recheck the password and try logging in again.

Figure 6: Login Page

Figure 7a shows the patient graphical unit interface (GUI) for the provision of patient clinical personal identification number for e-medical record unit after login. The GUI contains the identification number of patient waiting for consultation and time the patient clock in with graphical picture. Figure 7b shows the interface, after the medical record has entered the patient clinic identification number. The list of patients with related number is displayed on Figure 7b.

Figure 7a: Personal profile page of the system registration

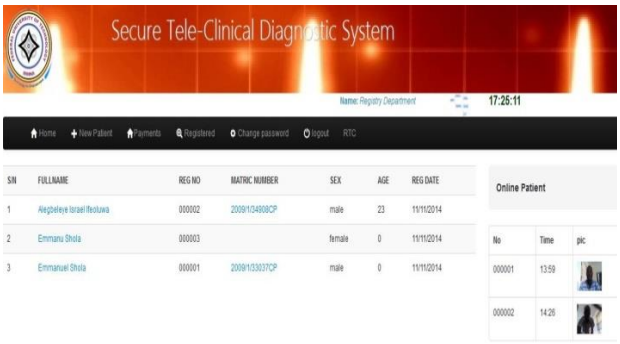

Figure 7b: Registered list of patients.

The interface on Figure 8a shows real time communication between practitioners and patient.

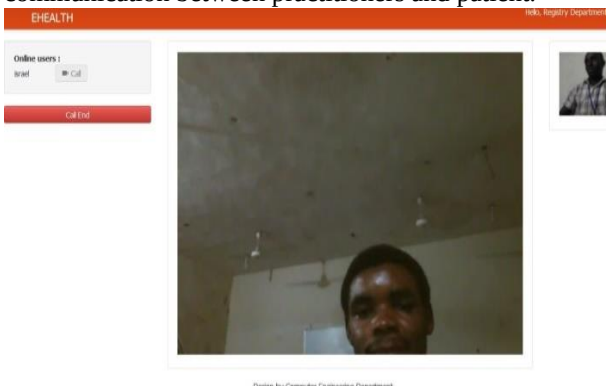

Figure 8a: Real time communication for Tele-consultations between medical experts and patient

Figure 8b shows an interface for Tele-diagnostic session between medical physician and patient. The right side of the screen shows the list of patients on the queue for consultation. The 'H' navigation contains tabs for history of complaints, doctor diagnosis, doctor examination, investigations, nurse administration, and operation note. The other black navigation contains tab to write case note on patient complaints, examinations, diagnosis, vital signs, prescription administer admission and check the payment invoice of the patient. From Figure 8b the medical doctor gives medical instructions to other units like nurse to administer treatment, prescription to pharmacy, investigation to laboratory and radiology.

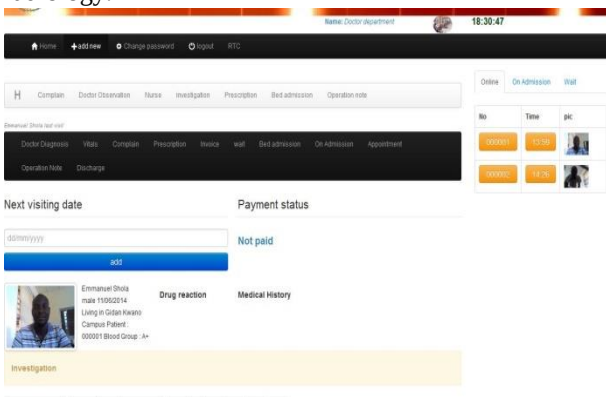

Figure 8b: Tele-diagnostic session between doctor and remote patients

Figure 9a and Figure 9b show the GUI for pharmacy to dispense drug. The GUI contains the category of drug available. The right hand side of the GUI contains the list of patient sent by medical doctor on prescription to the pharmacy unit.

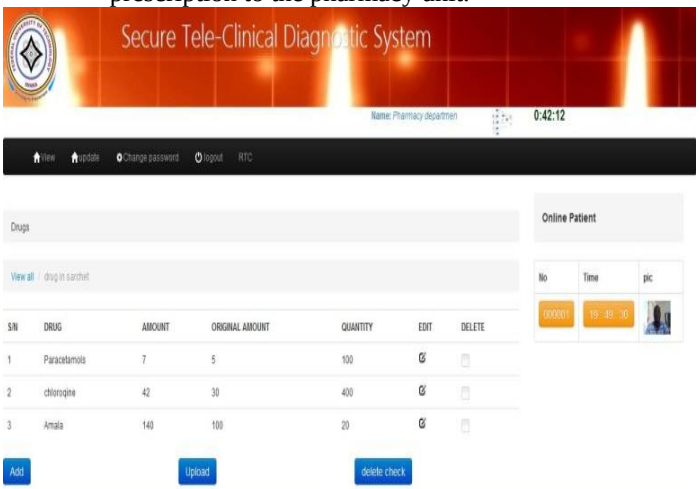

Figure 9a: Electronic dispensing of drugs to patient.

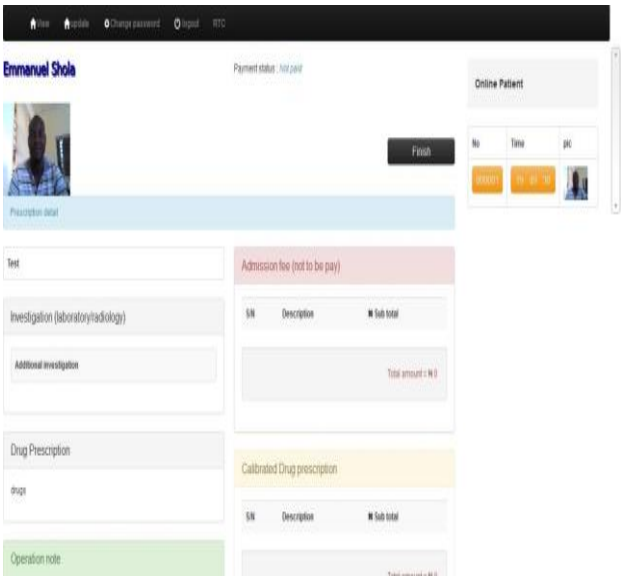

Figure 9b: E-Pharmacy GUI for dispensing drugs

Findings of the system performance evaluation from the assessment of confidentiality of the developed system as shown in Table 1 revealed that over seventy percent (70.72%) of the respondents cumulatively agreed that the developed system maintained the data secrecy as shown in secrecy and confidentiality. The findings of the system usability such as friendliness of the system when used by practitioners revealed that over ninety percent (97.55%) cumulatively agreed that the developed secure tele-clinical diagnostic system was user friendly. The findings of dependability of audio and video real time communication of the developed system revealed that over ninety percent (95.2%) cumulatively agree that the developed system real time communication was dependable. The billing management of the system accessed by the practitioners revealed that over eighty percent (85.36%) cumulatively agree that this system gives a correct financial report. The bar chart in Figure 10 shows the pictorial representation of the evaluation result presented in Table 1.

Table 1: Results of descriptive non-parametric data analysis of the respondents

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Cumulative Agreement (%)
User friendliness/Usability	11 26.82%	29 70.73%	1 2.44%	0 0	0 0	**97.55**
Real Time Communication	22 53.66%	17 41.46%	0	2 4.88 %	0	**95.2**
Billing Report	9 21.95%	26 63.41%	6 14.63%	0	0	**85.36**
Secrecy and Confidentiality	8 19.51%	21 51.21%	7 17.07%	4 9.76%	1 2.44%	**70.72**

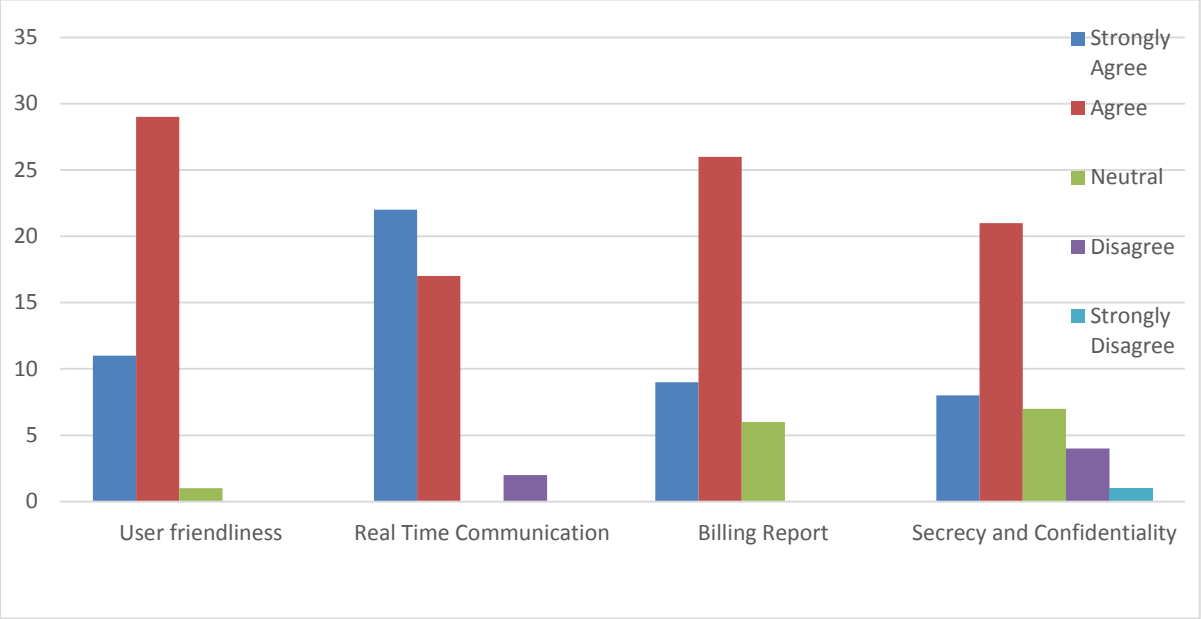

Figure 10: Bar chart representation of numeric frequency of response of Table 1.

Based on the earlier defined requirements, four performance evaluation metrics were formulated to establish the degree to which the system meets the requirements. These metrics are: SystemUsability Index (SUI) for usability requirement, System degree of confidentiality (SDC) for data confidentiality requirement, System degree of accuracy in billing (SDAB) for accurate billing and System degree of Real time Communication (SDRTC) for tele-consultation. Table 2 shows the summary of

Table2: Performance. Evaluation metrics of the developed Secure Tele-clinical diagnostic system

Performance Evaluation metrics	Response designation	Response Mean
System degree of confidentiality (SDC)	>3	3.76
System usability index (SUI)	>3	4.42
System degree of accuracy in billing. (SDAB)	>3	4.07
System degree of real time communication (SDRTC)	>3	4.44

CONCLUSION

In this paper, the requirement definitions, design, development and qualitative evaluationof a functional and secure tele-clinical diagnostic system for effective delivery of medical services to patient in a geographically dispersed academic environmenthave successfully been presented. The results of the developed system show that the synergistic combination of concepts of Telemedicine, Software engineering and Information Security in this study can significantly assists healthcare professionals to improve efficiency, trust, enhance work productivity and increase the operational speed of medical health delivery in developing countries like Nigeria. The developed system ensures the safety of patient data and service reliability in tele-consultation. The full deployment of the system at our test bed, Federal University of Technology Minna healthcare center and similar health care facility in developing countries is expected to improve practitioner's productivity and improve clinical healthcare like other medical devices like Stethoscope and Electrocardiogram machine. The development of Secure Tele-clinical Diagnostic System helps in carrying out diagnosis; manage patient data, consultation with the aid of information and Communication Technology regardless of location of the patient and health care center. This system can be improved by integrating RFID system to automatically identify enrolled patient and Information hiding techniques such as steganography and watermarking can be applied to improve confidentiality and integrity of patient data. It is recommended that future medical informatics and telemedicine professionals would provide seamless and secure solutions along these research directions.

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