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Research paper

Development of a Telepresence Robot with Integration of a General Practice Medical Consultation Module

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Abstract

The Philippines is facing a major problem in the healthcare industry—the maldistribution of doctors. This greatly affects people's accessibility to proper healthcare; in fact, in 2015, 59.2% of deaths in the Philippines are attributed as deaths unattended by a doctor. One viable solution to this problem is the use of telepresence robots, as doctors can still provide quality healthcare services even when located in remote areas. The researchers developed a mobile telepresence robot integrated with different physical examination equipment used in general practice medical consultation, which are an otoscope with a tested average video delay of 3.76s over VPN, a stethoscope with 5.19s audio delay (LAN), and an ultrasound probe with 6.32s video delay (LAN). The teleconsultation system also consists of a web-based application, which serves as a medium for the duplex communication, remote robot control, patient database access, and transmission of media footage captured by the physical examination devices. The developed web-based application had an overall relative efficiency of 93.58% and a System Usability Scale Score of 82.5, when used by invited medical professionals. The researchers believe that this will extend the reach of medical doctors to rural areas and improve the overall health conditions in these communities.

Keywords: *Electronic Health Records; General Practice Medical Consultation; Teleconsultation; Telehealth; Telepresence Robot*

1. Introduction

The maldistribution of doctors is a common problem in developing countries like the Philippines [1]. The current doctor-patient population ratio in the Philippines is 1:33,000 [2]. The low doctor-patient ratio is caused by the increasing number of doctors who choose to work overseas [3]. According to the Philippine Medical Association, only 70,000 of 130,000 licensed physicians are active in the profession due to working overseas [4]. Many medical practitioners prefer to work overseas, in the urban areas, or in other disciplines to meet their financial needs and have more career opportunities [3]. Maldistribution of doctors results to some hospitals and municipalities in the rural areas to have no assigned doctor. In fact, in 2005, 120 hospitals in rural areas have closed because there are no doctors [5]. In 2015, 59.2% of the total 560,605 deaths in the country is unattended by a doctor. The National Capital Region (NCR) is the only region with higher percentage of attended death (59.3%) compared to unattended death (40.2%). Region X Northern Mindanao has the lowest percentage of unattended death in rural areas (56.2%), while ARMM has the highest (70%) [6].

The low number of physicians working in rural areas and public hospitals causes imbalances in the delivery of quality healthcare services in these areas [7]. Currently, the government has different projects to address this problem and one of which is through the implementation of the program called *Doctors to the Barrios* [8]. Another viable solution to address this problem is the use of telepresence robots in hospitals and health centers in rural areas. The study by Gagnon et al. [9] provides a qualitative research about the insights of medical professionals regarding the impact of telehealth in clinical practices in Quebec, Canada. The results show that majority of the interviewed healthcare professionals believe that telehealth systems can bring positive impact on the quality of healthcare services in the rural areas as they provide better accessibility to healthcare, easier transfer of information between hospitals in case of patient transfer, and a better means of information exchange system among healthcare professionals [9].

A telepresence robot is defined as a computer-controlled robot with basic components consisting of a video camera, a screen, a microphone, and a speaker, which allow viewing and verbal exchange for both sides of the conversation [10]. Telepresence robots have various applications in the academic, business, household, and hospital settings. One application of telepresence robots in the medical field is in medical consultations; however, these robots lack medical features to provide better diagnosis and they only include means of talking face-to-face to a doctor using a real-time video projected by the robot. This shows the gap between the medical services provided by a present medical practitioner and a telepresence robot. That is why medical equipment should be integrated in order to improve the diagnostic capabilities of telepresence robots used for medical consultation.

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2. Design Methodology

2.1. Mechanical Design

The telepresence robot in this study had two major components: robot chassis and robot casing. These parts of the robot underwent the conceptualization and designing stage before fabrication. This section will discuss some of the considerations and the fabrication stages of these major parts.
There was a need for the telepresence robot to have an empathic design to increase the patients' acceptance of the system. The key criteria in designing this robot was to make it as non-human-like as possible because according to a study [11], making it more human-like raises false hopes and expectations on the abilities of the robot that it cannot fulfill, and this makes it less attractive and less acceptable for the users. Also, according to the same study, animal-inspired embodiments are most suited to the healthcare industry as they exude care-taking behaviors from humans; and it is because of this that the design of the robot incorporated some of the characteristics of a penguin. This is supported by a robot chassis made of slotted galvanized steel angle bars. The frame also holds the electronic panel, and dc motors and ensures the robot is in balance, especially while in motion.

Fig. 1: Actual Photo of Akibot

The robot height was derived from the asian ergonomic sitting height of 115.68cm (45 inches) [12]. The screen is attached to an adjustable bracket which can cater to wide variation of filipino sitting height. This is because the majority of the teleconsultation is done while the patient is sitting down. The compartment for the medical devices is made easily accessible by placing it in front of the robot body where it is within a hand's reach. Please see Appendix A for the technical drawing with more specific measurements. Figure 1 shows the actual photo of *Akibot*, which is the designed and fabricated remotely controlled telepresence robot with integrated physical examination devices.

2.2. Electronics

In developing the mobile telepresence robot, there were a lot of electronic components used such as a microprocessor, a microcontroller, the motor drivers, and different power supply components like the battery, the power distribution module, and DC voltage regulators.

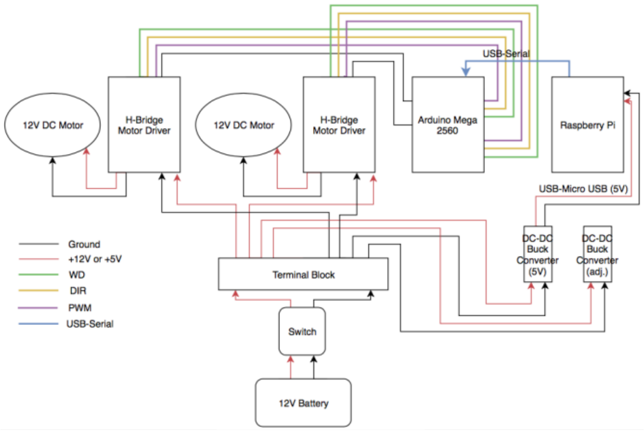

Fig. 2: Schematic Diagram of Power and Data Lines

In Figure 2, the positive and ground lines of the 12V battery are connected to one side of the terminal block, which powers the two H-Bridge motor drivers and the two DC-DC buck converters. Each motor driver is connected to the +Vin and GND lines of the DC motor and the WD, DIR, and PWM pins to the corresponding Arduino pins (e.g. pins 2, 4, 3 for the left motor and pins 5, 7, 6 for the right motor).
The fixed 5V USB DC-DC buck converter regulates the input voltage of 12V from the power supply and supplies a constant voltage of 5V to the RPi. The RPi then supplies power and data to the Arduino via the serial port of the microcontroller. It is through the serial communication that the RPi is able to send commands to the Arduino for the telepresence robot to perform certain robot movements.

2.3. Medical Devices

Besides the electronic components, there are other equipment that make up the system of the developed telepresence robot. These equipment include the different physical examination devices, which were integrated into the telepresence robot to improve its diagnostic capabilities.
For this study, a 720P USB Otoscope 3 in 1 Digital Ear Endoscope was used. It is equipped with 5.5 mm camera with 6 adjustable LEDs, OV sensor, super clear image quality 14mm-20mm focusing, water resistant camera. Along with it is an LED adjusting wheel, which helps improve camera image brightness and clarity even in low-light condition.
The digital stethoscope used in this study is the ChildCare Cloud Stethoscope developed by a startup Shanghai Tuoxiao Intelligent Technology Co., Ltd. based in China. The stethoscope composes of medical piezoelectric sensors with heart and lung modes and a sampling rate of 44.1 kHz. This product is designed to use auscultation to capture the moist crackles from children with pneumonia [13].
Lastly, the ultrasound probe used was a convex ultrasound transducer type. The beam shape is convex and the transducer is ideal for in-depth examinations. The convex transducer for 2D imaging has a wide footprint and its central frequency is 2.5MHz – 7.5MHz, which can be used for abdominal examinations, transvaginal and transrectal examinations, and diagnosis of organs. The digital ultrasound probe works at the central frequency of 3.5MHz (2.5-4.5MHz) and a scanning depth maximum of 240mm.

2.4. Software

HTML5 is the standard markup language used for the front-end development of the web-application. Bootstrap, a CSS framework was used for the design of HTML templates to create responsive web pages. Javascript was also used to customize the attributes of forms, show web page in another window, and access the address of different medical devices. Flask, on the other hand, which is a Python web-framework, was used in the back-end development of the web-application. The process flow of the web application is shown in Figure 3.

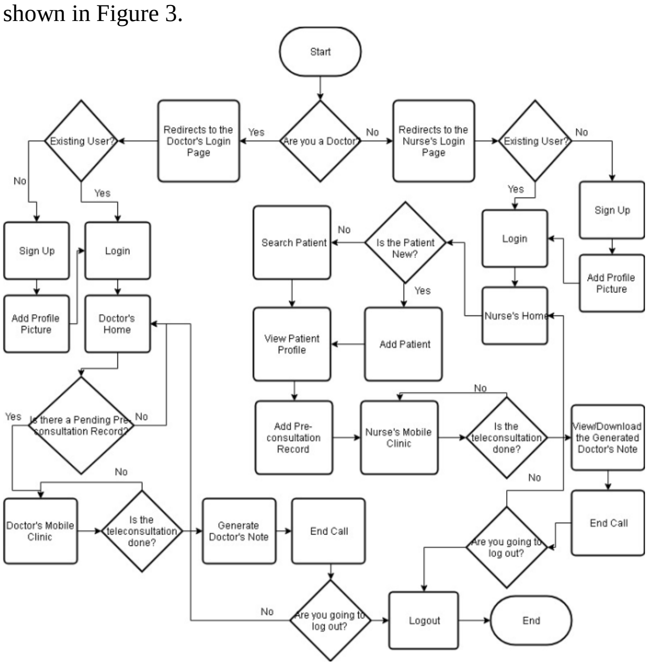

Fig. 3: Web Application Process Flow

To manage the data gathered in web app forms, MySQL database was used as the database system and was connected to the web application through Flask to allow adding and viewing of user and patient details, and storing and downloading of files.

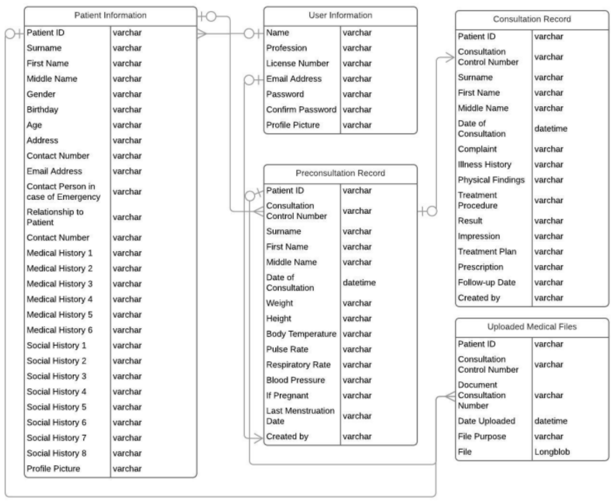

Fig. 4: MySQL Database Relationships

Different tables were created within the database for the user information, patient information, pre-consultation record, consultation record, and medical files. A unique Patient ID and Consultation Control Number were generated to provide a unique relationship among the tables. Figure 4 shows all the tables in the database, the information acquired in each column, and the relationship of tables with one another.

Figure 5 shows the data transmission lines between the different components of the system, clustered into the patient's side, the doctor's side, and the data hub. First, the web-based application is launched to the local network, which can be accessed by both the Android tablet in the patient's side and the doctor's computer. The robot control line initializes when the RPi has launched the command socket program. Once launched, the doctor's computer can send a command through the web-app that gets sent to the RPi. The Raspberry Pi then sends the command to the Arduino using serial connection, and the motors move accordingly through the motor drivers.

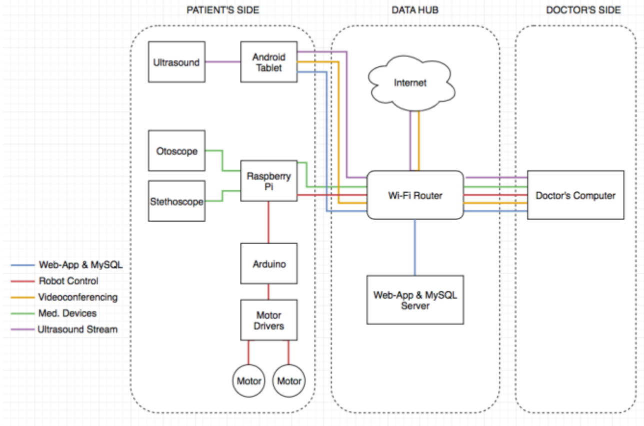

Fig. 5: Schematic Diagram of Data Transmission Lines

It is through the embedded WebRTC platform (Appr.tc) that the doctor's computer and the Android tablet in the patient's side are able to have duplex communication over the internet. The video and audio feed of the otoscope and stethoscope, respectively, are broadcasted to the local network by the RPi and can be accessed by the doctor's computer. Lastly, the Ultrasound attached to the Android tablet can be shared with the doctor through the screen-sharing feature of AirDroid over the internet. As for the Virtual Private Network (VPN) setup, the study made use of LogMeIn Hamachi, which is a hosted VPN service that allows users to extend local area networks to different teams securely, since its communications are secured using AES 256-bit encryption.

3. Analysis and Discussion of Results

According to the tests for both audio and video delays, it can be seen that the videoconferencing feature of the web-application is still functional at both low and high internet speeds.This is also the case for audio transmissions for either the patient side or the doctor side.

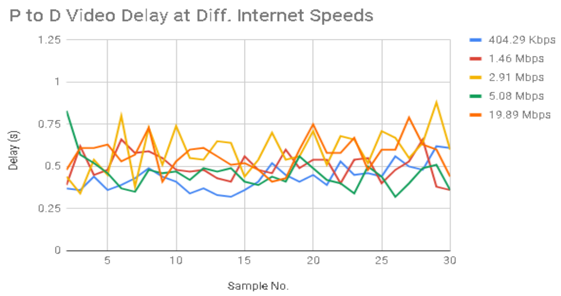

Fig. 6: Video Delay at Different Internet Speeds

This is further shown in Figure 6, where the video delay is plotted vs internet speed, and it is evident that the internet speed has no direct effect on the delay on the video.

In the delay in Figure 7, the device itself may be the cause of it, or that the internet speed recorded at the patient's side during the LAN test, which was only 10-15 Mbps (accdg. to Fast.com) was much slower than during the VPN test, which was at 38-44 Mbps.

Compared to the other devices and transmission, the otoscope video transmission seems to be the outlier, because unlike others, the LAN setup has significantly more delay and more drastic fluctuations. As for the Stethoscope feed, the audio delay over LAN is consistent with an average of 5.19s, started from 4.91s to a maximum of 47.51s. Lastly, for the ultrasound feed, the VPN setup had significantly more delay than the LAN setup.

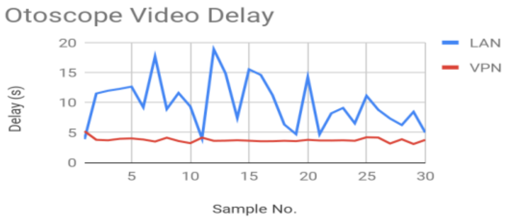

Fig. 7: Otoscope Video Delay

This may be attributed to the bandwidth allocated to the connection as this study had only used a free version of a VPN service, where the bandwidth is limited. This was done at the internet speed of 10-15 Mbps for LAN setup and 5-10 Mbps for the VPN client (doctor's side) and 10-28 Mbps for the VPN server (nurse's side).

Moving forwards, the delay in the robot's movements in relation to the command being sent by the doctor plays a crucial part in the system's overall ease of use. That is why the time it takes for the robot to move a certain way, given the command from the doctor was recorded over 30 samples, both in the LAN setup and the VPN setup.

Table 1: Average Delay per Command

Forward Delay (s)		Backward Delay (s)		Left Delay (s)		Right Delay (s)		Stop Delay (s)	
LAN	VPN	LAN	VPN	LAN	VPN	LAN	VPN	LAN	VPN
1.34	1.68	1.38	1.68	1.32	1.54	1.32	1.58	1.25	1.36

The delay in the VPN setup could be caused by a number of factors, one is the quality of the encryption, since better encryption could mean greater hit to the speed of data transfer. Another is the the quality grade of the VPN service provider; in this case, the study utilized only the free version of the VPN service, which limits the devices up to five only, and the fact that this limit has already been reached may have affected the bandwidth negatively as well. Lastly, the physical location of the server may have also affected the latency of the connection, where, during the experiment, the server was set in Manila while it is being accessed by a client in Laguna.

Table 2: Summary Statistics for Survey Items on Robot Control

Survey Questions	Mean	S.D.
Robot Control (Cronbach's Alpha = 0.73)		
The robot control feels intuitive to use.	4.4	0.68
The robot control makes me feel confident that I will not bump into things.	3.8	1.18
Controlling the robot becomes easier after a few tries.	4.3	0.87
The delay in robot control significantly affects the maneuverability of the robot.	4.1	1.13
Overall, I am satisfied with the robot control function of Akibat.	4.3	0.73
Notes: Individual items ranged from 1 = strongly disagree to 5 = strongly agree, scales constructed by taking mean of items.		

The survey items for respondents' impression on robot control function is reliable. The respondents agreed that they were satisfied with the robot control function of the robot. It could be inferred that the respondents were almost neutral in terms of perceived confidence when controlling the robot and that delay affects the maneuverability of the robot.

The usability of the web-based application were tested by three medical professionals. A training was conducted explaining the whole telepresence system, and making a demonstration on how the web-application works. After which, the participants were given different set of tasks covering all functionality of the web-application in both nurse's side and doctor's side. The usability of the web-application is measured terms of errors, completion rate, overall relative efficiency, User satisfaction, and System Usability Scale score.

Throughout the experiment, the subjects committed a total of 16 errors, 15 of which were committed on the nurse's side. There were more errors in the nurse's side compared to the doctor's side because laptops are easier to use than tablets, especially when filling up forms.

The completion rate and overall relative efficiency of the web-application were measured as the medical professionals performed different tasks covering all the functionalities of the web-application. The completion rate of the nurse and doctor tasks are 94.44% and 93.33% respectively, while the overall relative efficiency of the nurse's and doctor's tasks are 95.67% and 91.49% respectively. In the nurse's side, 17 out of 18 tasks were completed while 14 out of 15 tasks were completed in the doctor's side. One out of three subjects was not able to complete ultrasound-related task from both nurse's and doctor's sides.

The last metrics for overall usability of a web application are perceived satisfaction and the System Usability Scale(SUS) Score. According to the results, that the 3 users agree that they were satisfied with how they have accomplished their tasks. According to the SUS calculation given the results above, the web-application garnered a score of 82.5 over 100 points, which means that it is highly usable given that the normal average SUS score is 68 points [14]. The medical professionals' overall perceived impression on the web-application was that it was very easy to use.

Table 3: Summary Statistics for Survey Items on Robot Appearance

Survey Questions	Mea	S.I
Robot Appearance (Cronbach's Alpha = 0.75)	4.6	0.6
I am comfortable with the machine-like features of the robot.	4.8	0.4
The robot's appearance makes me feel safe.	4.6	0.6
I am not intimidated by the robot's appearance.	4.5	0.7
Overall, I am pleased with the appearance of the telepresence robot	4.7	0.6
Notes: Individual items ranged from 1 = strongly disagree to 5 = strongly agree, scales constructed by taking mean of items.		

As seen in Table 3, the overall perceived impression of respondents towards the robot appearance was that it was not intimidating but pleasing, and almost strongly agrees therefore that it has an empathic design. The survey items regarding the robot's appearance was reliable based from its cronbach alpha.

4. Conclusion

This study was able to accomplish a unified teleconsultation system that is able to run through LAN or VPN and has the following essential components:

Akibot - A remotely controlled telepresence robot with integrated medical devices and a tablet screen to be used on the patient's side.

- With an overall pleasing and empathic exterior design.
- With robot control functions that are easy to use and is easily maneuverable.
- Is able to transmit otoscope video feed to doctor's side and stream with quality that is usable for a general practice medical consultation, and average delay of 9.88s over LAN and 3.76s over VPN.
- Is able to transmit stethoscope audio output to doctor's side and stream with average delays of 5.19s over LAN and 19.79s over VPN.

- Is able to transmit ultrasound video feed identical to the source with average delays of 6.32s over LAN and 14.60s over VPN.

Akibat Mobile Clinic - A web-based application using a Flask library that serves as the main user interface for all the Nurse and Doctor functions.

- Doctor functions: video conferencing, remote robot control, checking of medical devices feed, viewing of current patient's profile, and generating a "Doctor's note".
- Nurse functions: adding, searching, or viewing of patient profiles in the patient database, videoconferencing, uploading of medical files, and viewing or downloading of "Doctor's Note".
- A responsive html template that could adapt to numerous screen sizes.
- With the following results on usability metrics: completion rate of 93.89%, over relative efficiency of 93.58%, highly satisfied users, and high System Usability Scale Score of 82.5 [15][16].

Wireless Data Hub - A wireless server that hosts the web application and manages the medical information using MySQL database.

- A structured medical database for storage and retrieval of the following sets of data: user information, patient information, pre-consultation records, consultation records, and medical files.
- Can be hosted using LAN and VPN connections.

In the future, machine intelligence such as artificial neural network [17] will be utilized for internet communication of multiple telepresence robots.

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