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Cost-Effective Medical Robotic Telepresence Solution using Plastic Mannequin

Victor O. Matthews, Segun I. Popoola, Emmanuel Adetiba, Joke Badejo, Aderemi A. Atayero
Department of Electrical and Information Engineering, Covenant University, Ota, Nigeria

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ABSTRACT

Robotic telepresence is an Information and Communication Technology (ICT) solution that has a huge potential to address the problem of access to quality healthcare delivery in rural areas. However, the capital and operating costs of available systems are considered to be unffordable for rural dwellers in emerging economies. In addition, most of these communities are not even connected to the power grid. In this paper, the authors reduced the cost of engaging a robotic telepresence solution for rural medicare by using plastic mannequin and solar photovoltaic technology. An IP camera was fixed in each of the eye sockets of the plastic mannequin. These cameras are connected to a mini-computer embedded in the plastic mannequin. A Wi-Fi module establishes an Internet connection between remote physicians and rural heathcare facilities. The system is powered by a solar photovoltaic energy source to guarantee power availability. Another unique feature of this solution is that it gives the patient a better impression of the physical presence of a physician. Comparative cost analysis with robotic telepresence available in the market showed that our system is more affordable. This development will increase the adoption of robotic telepresense in rural telemedicine.

Corresponding Author:

Segun Isaiah Popoola,
Department of Electrical and Information Engineering,
Covenant University,
PMB 1023, Ota, Nigeria.
Email: segun.popoola@stu.cu.edu.ng

1. INTRODUCTION

Modern ICT technologies can be readily harnessed to handle the challenges militating against quality healthcare delivery in rural areas. There is usually shortage of qualified medical personnels in remote health facilities. The cost and risk associated with travelling over a long distance to seek medical attention in urban centers is also high. Overdependence of rural dwellers on health facilities in the cities can increase mortality rate in cases of emergency. It is, therefore, necessary to leverage available technologies to provide urgent solution to this problem.

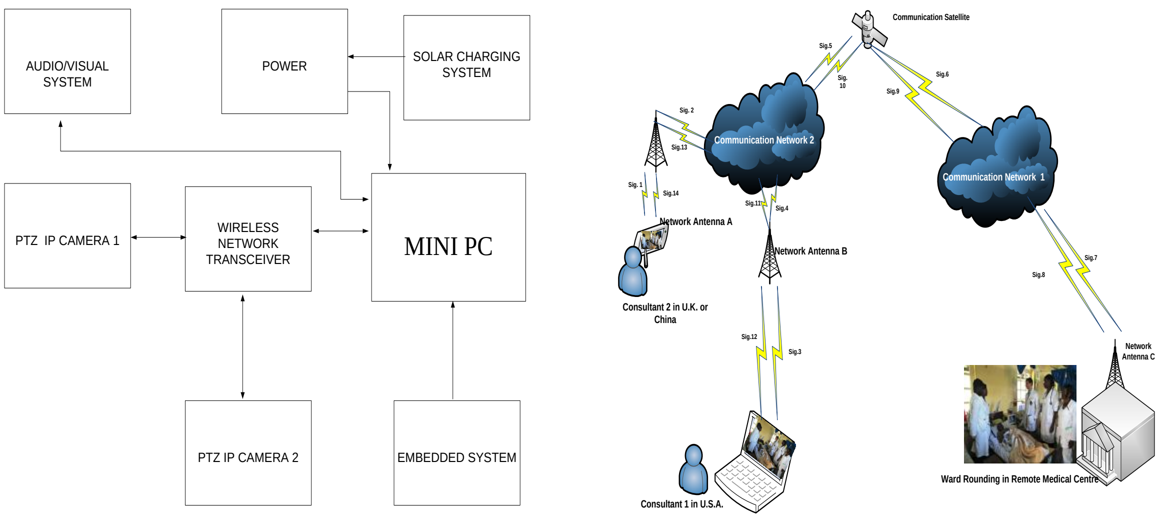
Telepresence is one of the innovative solutions for telemedicine applications. The World Health Organization (WHO) [1] defined telemedicine as "*the delivery of health care services, where distance is a critical factor, by all health care professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for the continuing education of health care providers, all in the interests of advancing the health of individuals and their communities*". Communities with inadequate healthcare infrastructure and personnels can adopt the use telemedicine applications to augment their deficiencies. Geographical barriers are commonly encountered when trying to connect patients to specialists in referral hospitals that are not in the same physical location [2]. Real-time video telecommunication capabilities of telemedicine [3] will assist health workers, medical consultants and specialists to deliver health care services to patients living in remote areas. The service may be in form of direct patient care, health education, and clinical consultation in critical care, transmission of dermatologic or radiologic images, or real-time video distant-monitoring support in the intensive care unit [4].

Several telepresence initiatives have been developed for health care applications. Remote tele-consultative service offered in [5] using a two-way audiovisual link produced a better clinical and educational effect than the telephone [6]. eICU [7], a dedicated facility designed for intensive care unit, allowed a consultant to supervise and monitor patients in different locations at the same time, reducing mortality and cost [8, 9]. Telemedicine have been applied for trauma and neurology consultative services where there are no resident specialist [10-14]. Despite the advances in this technology, its adoption among underserved population has been very limited. Major hindrances include the problems of complex human and cultural factors [15], lack of proof of economic benefits and cost-effectiveness, and legal considerations [16-18]. Robotic telepresence is a form of telepresence that creates an impression of the physical presence of an object at a remote location. This feature is accomplished through a mobile robotic mechanism with real-time audiovisual communication capabilities [19-26]. Considering the high level of extreme poverty in emerging economies, most of the available solutions designed to overcome this challenge are relatively unaffordable for deployment in this region. Also, the unreliability of power grid in rural areas where most communities are not even connected, will eventually hamper the sustainability of the whole system.

In this paper, the authors reduced the cost of engaging a robotic telepresence solution for rural medicare by using plastic mannequin and solar photovoltaic technology. An IP camera was fixed in each of the eye sockets of the plastic mannequin. These cameras were connected to a mini-computer embedded in the plastic mannequin. A Wi-Fi module establishes an Internet connection between remote physicians and rural heathcare facilities. The system is powered by a solar photovoltaic energy source to guarantee availability. Another unique feature of this solution is that it gives the patient a better impression of the physical presence of a physician.

2. RESEARCH METHOD

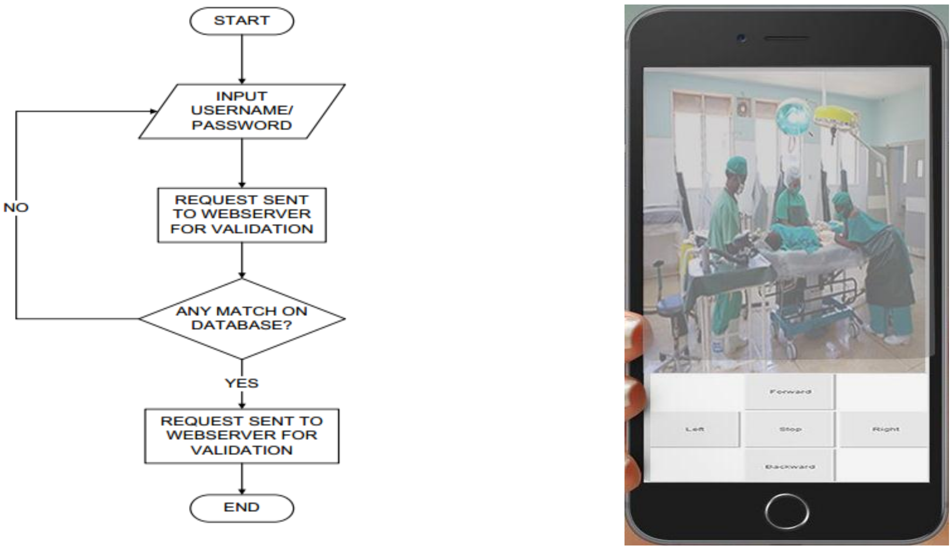
The plastic mannequin-based telepresence is a robotic system that is remotely controlled using a web-based software application that runs on the Internet. The hardware part of the system include two IP cameras, mini-computer, wireless network transceiver, and audiovisual system. These are enclosed in a plastic mannequin. This computer humanoid approach is employed to give a better impression of the physical presence of the medical consultant to the patient. The utilization of a plastic mannequin, which are relatively cheap, will significantly reduce the overall cost of the robotic system. To fully maximize the advantage of this method, the plastic head can be remolded to depict the face of the medical practitioner attending to the patient from a remote location. The plastic mannequin is dressed in the regular attire of health worker on duty.



(a) (b)

Figure 1. (a) Block Diagram; (b) Use Case of Plastic Mannequin-Based Telepresence

An IP camera is a network-based camera of high definition with the capability to pan, tilt, and zoom, and transmits data over the Internet. It enables easy access and real time human interactions when the integrated web server is connected to the Internet. There is a high degree of freedom of movement that enables views from different directions and multiple angles. This makes it ideal for continuous object tracking. Users can conveniently zoom in on a farther object for better view. In practice, this type of camera produce irregular response time to control commands, low frame rate, irregular frame rate due to network delays, varying field of view that results from panning, tilting, and zooming, and different scales of objects. However, with the adaptive fuzzy particle filter algorithm proposed in [27] the displacements in the image plane between two consecutive frames is reduced, and the detected target location is near to the ground-truth. By this, the camera exhibits a better precision on focus. Of the two cameras fixed into the eye sockets of the mannequin, one is intended to enable remote access for a distant-consultant while the other is reserved for a specialist. This is aimed at facilitating professional collaboration to boost the quality of healthcare delivery in the rural areas of developing nations. The IP cameras are securely accessible to the health professionals via a web server application. A low-cost, energy-efficient IP camera such as shown in Fig. 3 is made up of a video pre-processing unit, an H.264 encoder, and an embedded streaming server [28]. The video data is acquired and properly formatted by the video pre-processing unit. The output of the pre-processing unit is compressed with H.264 baseline encoding tools, and a continuous flow of data is ensured by the streaming server for the Internet video communication. Based on cheap and power-efficient Blackfin Digital Signal Processor (DSP) and ARM9 processors employed in the encoder and the streaming server, and optimal use of the DSP resources, the IP camera delivers Common Intermediate Format (CIF) or Video Graphic Array (VGA) size of real-time video clips directly to the Internet with high Peak Signal-to-Noise Ratio (PSNR) quality and low bit rates. This improves video quality at reduced bandwidth, and makes the system more reliable.



(a) (b)

Figure 2 (a): Flow Chart of Web Server Operation; (b) The mobile Application Platform

For the audiovisual sub-system, a microphone is fixed on the neck section of the mannequin. With this, the remote users can easily pick up acoustic signals from the clinical ward for effective communication. The microphone is sensitive to vibrations, thus providing good acoustic quality. The well-perforated chest part of the mannequin houses the speaker. A four-wheel movement support is designed at the base carriage, and operated by a 12-volt DC electric motor. The program codes of the system is loaded to a mini-computer located within the plastic mannequin. Raspberry Pi, an 85.60 mm x 53.98 mm x 17 mm single-board computer, performs computations with much less power consumption compared to desktop computers, laptops, tablets and smart phones [29]. The low-cost mini-computer has general-purpose input/output universal serial board (USB) ports (1 to 4) for connections to external devices. Latest release, Raspberry Pi 3 Model B, is equipped with RAM (256 MB to 1 GHz), on-board Wireless LAN (Wi-Fi IEEE 802.11n), an 8P8C Ethernet port and Bluetooth. It also features a central processing unit (CPU) with speed range of 700

MHz to 1.2 GHz, and a graphic processing unit (GPU). The price of the advanced model varies between US $20-35. The operating system and application programs are stored in secured digital (SD) cards of SDHC or micro-SDHC sizes. The system also has a HDMI and composite video output alongside a 3.5 mm audio jack for audiovisual communications. The mini-computer is connected to the Internet via a Wi-Fi communication link established between a high-speed access point and Wi-Fi adapter of the mini-computer. Remote users can easily log in to the system using different platforms such as smart devices, desktop computers, laptops, PDAs etc. Few community health workers available at rural health facilities will assist the medical experts in collecting vital health information and records of patients. The system allows real-time audiovisual communication between the medical professionals, the community health workers, and the patients. The pan-tilt-zoom capability of the IP network cameras enables the remote consultant and specialist to gain a complete view of the hospital ward, and if necessary zoom in to focus on a particular part of the body of the patient with no assistance from the community health workers.

A client-server model was used for the web server and Hypertext Transfer Protocol (HTTP) forms the webpages. This module links the remote user to the robotic telepresence system. The Apache webserver runs on a dedicated computer. An obstetricians based in any of the developed countries, say United States of America, with a pre-assigned authentication code can log in to the electronic platform to attend to different patients at different rural health facilities. Several other specialists/consultants (pediatricians, anesthesiologists, critical care medicine specialists, gynecologists etc.) can also attend to patients in different wards of remote clinics during routine ward rounding. Data signal is transmitted from the smart device or internet-enabled personal computer of the remote medical experts and it is routed through the internet cloud to connect to the system. With a reliable internet connection setup at the rural clinic, the specialist/consultant gains remote control of the robotic system with ease. The movement of the mannequin is guided by the audio-visual information that is clearly available to the user. The user communicates effectively with the assisting community health workers as well as with the patients through an open-source remote viewer software. This publicly available software is employed to further decrease the cost of deployment.

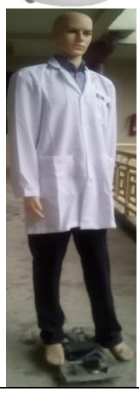
Wireless Fidelity (Wi-Fi) utilizes unlicensed spectrum band to increase broadband internet access which can promote health care service delivery to underserved populations. The use of unlicensed frequency allows hospitals to set up links anywhere, anytime as they deem fit, thereby improving sustainability. Large networks can be deployed with IEEE 802.11 after a little changes to the MAC layer. This will enable Wi-Fi transceivers to work effectively especially at very long distances. Cost-effective network model adopted in [30] has proven the feasibility of the deployment of Wi-Fi over Long Distances (WiLD) and femtocells in achieving broadband internet services in rural areas with acceptable Quality of Service (QoS). Wi-Fi communication technologies operate at different frequencies to deliver maximum data rates. For sustainable Internet services in third world countries, a solar-powered Wi-Fi technology will allows villagers to send signals through an IEEE 802.11 b connection [31].

Nowadays, most of the advanced technologies available to improve way of living are electricity-dependent. Unfortunately, most of the rural areas in the developing world are not connected to the power grid. For instance, in Nigeria, the majority of the less than 40% that are currently connected to the grid are located in the urban centers [32, 33]. According to United Nation, rural population in Nigeria constitutes approximately 50.4% [32]. Out of this, only 36% are connected to the grid, with not up to four-hour daily supply [34]. In that case, many of the ICT-driven technological solutions have not been efficiently deployed for underserved populations [35]. Whereas, rural communities have about 90% renewable energy potentials that are not yet optimally harnessed [36]. The exploitation of alternative sources of energy will aid rapid penetration of ICT-driven technologies for sustainable development in remote locations where accessibility has become a serious challenge. Solar energy and wind energy options are becoming increasingly popular for low and medium power applications in rural community projects [37-39]. Olatomiwa et al. [40] investigated the potentials of wind and solar energies and the optimal configurations of hybrid renewable system for rural health clinic applications in grid-unconnected rural villages within the selected locations covering the six-geopolitical zones of Nigeria. The authors [40] reported that the hybrid system configurations yielded better results than running on diesel-only, with the unique advantage of electrical, fuel consumption and CO_2 reduction. Therefore, the system is powered by a solar photovoltaic energy source to guarantee power availability.

3. RESULTS AND ANALYSIS

Table 1 shows the prices of available robotic telepresence systems. A cost comparative analysis showed that the plastic mannequin-based telepresence is more affordable with better efficiency. In this sense, emerging economies can take advantage of the cost-effectiveness that this system offers to resolve the challenges facing rural medicare in the region.

Table 1. Robotic Telepresence Systems

Product Name		Manufacturer	Price
Beam + Smart Presence System		Suitable Technologies (https://suitabletech.com/beampro)	$1,995.00
Double 2 Telepresence Robot		Double Robotics (http://www.doublerobotics.com)	$2,499.00
Kubi Telepresence Robot		Kubi (https://www.kubi.me)	$1,907.00
VGo Robotic Telepresence System		VGo Communications (http://www.vgocom.com)	$5,995.00
AMY Robotic Telepresence		AMY Robotics (http://www.amyrobotics.com)	$6,999.00
Plastic Mannequin-Based Telepresence		Embedded & Telecommunications Lab, Department of Electrical and Information Engineering, Covenant University, Ota, Nigeria (www.covenantuniversity.edu.ng)	$456.00

4. CONCLUSION

Mobile robotic telepresence is an expensive healthcare solution for people living in rural areas. Most rural dwellers in emerging economies are extremely poor and cannot afford the cost of service of a robotic telepresence. We have reduced the cost of engaging a robotic telepresence solution for rural medicare by using plastic mannequin and solar photovoltaic technology. The plastic mannequin-based telepresence utilizes two IP cameras with the ability to communicate over the Internet using Wi-Fi transceiver module available on a mini-computer. This successfully minimized the overall cost of the system. Also, the system was designed to operate on solar PV system to ensure availability of required electrical power at low cost. After a proper authentication process, a medical consultant based in any of the developed countries can easily log in to the web or mobile application platform and attend to patients in different parts of the developing countries where the mannequin robot is situated. The developed system allows other specialists/consultants to work seamlessly with the community health workers during routine ward rounding. Patients seems to be more comfortable with a real human figure during treatment rather than relating with a typical machine appearance. In clear departure from existing robotic telepresence systems, our solution gives a better impression of the physical presence of a medical personnel. Compared to existing telepresence robot, the plastic mannequin-based system is a cost-effective, energy-efficient, and eco-friendly solution that has an enormous potential to significantly increase the adoption of robotic telepresense in rural telemedicine.

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