AN INDIGENOUSLY DEVELOPED AFFORDABLE AND SUSTAINABLE TELEMEDICINE SYSTEM

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Abstract

Telemedicine offers a solution for providing expert medical care to rural people in the Third World. However, indigenous development of necessary equipment is essential for affordability to a large number of centres in the country and for sustained service. The present work reports indigenous development of five items of equipment and necessary software for a microcomputer based telemedicine system in Bangladesh rural health complexes established by the Government. The items are: Stethoscope, X-ray viewbox, Microscope, 12 lead diagnostic ECG and Colposcope, and all data can be sent in real time. If the system succeeds it will be a model for the Third World countries.

1 Introduction

Making expert doctors available at rural centres in the Third World is still a far cry. Telemedicine using modern microcomputers and mobile phones appears to offer a solution to this problem. Bangladesh Government has already established 800 rural health complexes with X-ray, Pathology, basic surgery and other relevant facilities. However, due to socio-economic conditions, it has proved very difficult to keep well qualified specialist doctors in most of these health centres. Therefore, a telemedicine system with knowledgeable specialist doctors at city expert centres, and trained junior doctors, paramedics and technicians in the rural centres can make a big change in the rural healthcare scenario. The Bangladesh Government has already established computers and internet facilities with video capability in all these rural health complexes, which is being used mainly for management and for a rudimentary telemedicine through video and audio means of communication. A full-fledged telemedicine system with digital versions of several diagnostic equipment linked to a microcomputer would be the next improvement, however, doing this using imported equipment proved to be prohibitively expensive. Besides, because of repair and maintenance problems with imported equipment it will be impossible to provide continuous and sustained service. Any problem will suspend the service for months, if not years.

Considering the sheer number and physical remoteness of these rural centres in the country, unless the equipment are developed and made at low cost within the country, it will be impossible to make this attractive solution of telemedicine in reality. The authors therefore took up this project for development of necessary hardware and software solutions.

A telemedicine system requires a set of computer interfaced diagnostic equipment at each of the rural centres together with necessary software for sending and receiving the data, for some cases in real time, through the internet. In order to provide a solution in this regard, we have indigenously developed five items chosen through consultation with field experts of the Government. These are: stethoscope, X-ray viewbox, microscope, ECG (12 lead, diagnostic quality) and colposcope (for viewing of cervix, to detect cancer) [1].

Two approaches have been taken in this regard. Firstly, improvisation of the necessary equipment through modification of commonly available products, not necessarily meant for medical use. Secondly, development from scratch where needed. A high quality webcam (Logitech Quickcam Pro 9000) with Carl-Zeiss glass lens, 2M-pixel native resolution and 4x digital zoom was the backbone of the units requiring picture capture. This ensures a high quality of the images, optimised for transmission through limited bandwidth of internet.

The ECG equipment was developed from scratch. An interesting point surfaced during this development. Although the ECG equipment was invented more than 100 years ago, and all the 12 leads were standardised more than 50 years back, no detailed circuitry for the network and switching needed at the front end for the 12 lead configuration could be found, even after a thorough search in the internet. Basic circuitry for the ECG amplifier was available generally, but not for the front end. It seems that these information remained ‘secrets’ of the manufacturers who carried out their own R&D. For the indigenous ECG equipment the whole circuitry was designed from basic knowledge of the science involved. Therefore, this information emphasises the necessity for indigenous R&D in each Third World country. The added benefit is that the necessary expertise is developed through such R&D, which is necessary for quick repairs during the real life use of the equipment. A basic philosophy for the development was to use components and parts available in the local market unless some special ones are absolutely...
necessary, or if the use of a special imported component make the device very cheap and significantly easy to manufacture.

2 Methods

2.1 Basic network

The basic network for the developed telemedicine system is shown in Figure 1. A central server connects to all the remote rural centres and the expert centres in the towns and cities. Any remote centre will be able to link to any expert centre and vice versa.

![Figure 1. Basic scheme for the telemedicine network](image)

At each of the rural health centres the equipment mentioned before will be interfaced to a Personal Computer (Local PC – microcomputer, Desktop, Laptop, etc.) through which the data will be sent to an expert centre via internet link. The local PC will also have facilities to monitor the picture, video or sound, to print out reports, and to store data and prescriptions for archiving. Data entry through keyboard also remains a part of the system which will be useful to enter patient details, temperature, blood pressure, etc. The rural health centres in Bangladesh have a separate high speed video conferencing link which will be an added advantage. However, in most cases, video link can also be established through the internet. A block diagram for the system in a remote rural health centre is given in Figure 2.

The diagnostic equipment developed in this work are presented below.

2.2 Digital Stethoscope

The digital stethoscope was improvised by inserting a low cost electret condenser microphone insert (6mm dia) into the tubing of a standard stethoscope by cutting the tube off at a convenient point as shown in Figure 3. The output of the microphone was connected to a standard coaxial cable and audio jack to feed the signal into a microcomputer. An open source software named ‘Audacity’ was found to be suitable to give the low frequency sound as needed for cardiac sounds (Figure 4). For transmission through internet in real time ‘GoogleTalk’ was found to be giving a good reproduction. Normal ‘Skype’ was not satisfactory for this requirement. ‘Audacity’ also gave the possibility of displaying the sound waves and storing the data which could be used to perform later signal analysis to extract further diagnostic information.

In the telemedicine application, a specialist doctor at an expert town or city centre will be able to see and instruct a paramedic placing the stethoscope on the patient through the video and audio link while listening to the sound in real time. This will facilitate diagnosis. For listening to heart sounds the lower part of the audio frequency is important, and normal
loud speakers available with desktop or laptop computers are not good at reproducing such low frequencies. A good quality headphone is a better solution which will be needed by both the paramedic placing the stethoscope on the patient, and the specialist doctor listening to the sound at the city health centre.

2.3 Digital Microscope

The digital Microscope involved fitting of the high quality webcam mentioned before to a standard microscope appropriately. The camera is like an eye; therefore, wherever an eye can see something, a camera can be fixed there. The camera therefore should be fitted onto the eye piece of the microscope, as close as possible. The alignment of the webcam to the microscope has to be very precise, otherwise the field of view of the microscope moves away from the image. The whole camera and the eye piece assembly were covered using an acrylic plastic box cut and made to shape. A Chinese microscope available locally at a cost of about US$100 was used. The webcam cost slightly less than US $100. The total cost was thus significantly lower compared to a commercially available digital microscope, even from China. On the other hand the quality is high because of the high quality webcam. The microscope had objectives with 10, 40 and 100 times magnification (the last one requiring oil immersion) while the eye piece used had a 10 times magnification. The product of these two magnifications gave total magnifications of 100, 400 and 1000 respectively. This combined with the continuously variable 4 times digital zoom of the webcam contributed to a large range of magnification.

The prototype microscope does not have a built-in light source. It has a circular mirror to reflect light from other sources. An LED rechargeable torch light is used to provide light if natural daylight is not available. However, this needed a diffuser which was made by cutting a 2mm thick opal white acrylic sheet and placing it in a filter mount available with the microscope model used.

At 2 MPixel resolution, a typical image requires about 500kBytes of data which can be transferred in reasonable time even with a slow internet bandwidth. The supplied webcam software has many facilities for exposure control, focusing, contrast control, digital zoom, etc. It also has a video recording facility with sound. Figure 5 shows the prototype digital microscope and two screenshots of an onion cell at different magnification, taken using this device.

The facilities available and the low cost make this microscope suitable for a wide range of applications besides telemedicine. Any pathological laboratory can use it for routine investigations relieving the specialist from straining the eyes. It can be used for student instruction as well where voice instructions may be recorded while making a video of the image. By projecting the computer output onto a large screen...
using a multimedia projector it is possible to use this microscope for pathological instruction and training in Medical Colleges, which otherwise needs expensive microscopes with multiple heads.

2.3 Digital X-ray view box

The digital X-ray view box was made up using black melamine covered particle board with a 4mm opal white acrylic sheet fitted at the top. A total of 215 white LED’s inside the box consuming about 20W was used to illuminate the opal acrylic sheet from below. On all the four interior walls of the box, an adhesive white plastic film was affixed to reflect light. The opal acrylic sheet at the top diffused all the incoming light to provide an almost uniform backlighted viewing frame. The webcam was fitted using a stand and clamp arrangement. The camera could be raised or lowered to view a larger or a smaller area of the X-ray image, thus providing a variable magnification. The digital zoom function of the webcam also provided further variable magnification.

This device could also be used as a photocopier of written documents using ambient lighting. Handwritten prescriptions and other paper documents relating to a patient can thus be copied, transmitted, and stored for archiving. Figure 3 shows the View box while a screenshot of a sample X-ray image taken using this device is shown in Figure 4. The quality of the reproduced image is of a good standard for diagnosis.

2.3 Digital Colposcope

A colposcope is used to detect cancer of the cervix through observation of a magnified image. A colposcope needs to focus the cervix from a distance of about 30cm, so that the doctor can carry out necessary operations by hand while viewing through the device. In a digital version the image is usually displayed on a monitor placed above or to a side of the patient. However, the camera with the magnification optics has to be in front of the object to be viewed, in between the doctor and the patient, so the requirement for focusing at about 30cm still remains.

To make up quality optics from scratch would be impractical in a Third World setting since getting readymade high quality achromatic optical elements with non-reflecting coatings of the required focal lengths from the local market will be absolutely impossible. It would be next to impossible even from a foreign market. It is only possible if someone orders these items from a foreign optical manufacturer. It can be easily guessed that this has to be a large volume order, which is not practical for a small Third World company. Therefore, we wanted to use consumer optical instruments available in the market, because these are produced in large volumes and the cost can be significantly low, compared to specialised professional products. Therefore, we avoided such specialised products as much as possible. For a start we looked at available standard telescopes and microscopes. None of these can focus to our required distance of 30 cm. So we procured a binocular telescope off the shelf, cut it out to two halves to make two monoculars (Figure 6), disassembled the eye piece, and reassembled it with an extended tubing of suitable length placed in between. This provided the required focusing to 30cm.

Figure 4. A view of the digital X-ray view box

Figure 5. Screenshot of a sample image taken using the prototype X-ray view box

Figure 6. Cut up binocular prism telescope as the building block of a colposcope.
In the next step the webcam was fixed onto the eye piece to produce a digital image. Two rings of white and green LEDs were also fixed around the objective lens for which necessary power supply and switching circuitry were designed and made up to make it as small as possible. The green light is needed to highlight the blood vessels which appear darker than that in white light, and is used in traditional colposcopes as well. The whole assembly was enclosed in a black acrylic plastic box made manually, only the power transformer for obtaining low voltage from the mains line voltage was fixed in a box separately.

Next came the challenge for mounting the device. Initially we used a microphone stand, but it was not easy to manoeuvre, besides, the tripod and stand came right in front of the doctor, making it an obstacle to the operations to be performed. Therefore, we wanted to use an easy to manoeuvre movable arm as used in dentist’s lamps and many medical equipment. Getting such a spare from a medical supplier was difficult in the local market. Again, instead of attempting to make such a mechanical contraption from scratch, we purchased a desk lamp holder with spring loaded hinged arms that is available in the local market at low cost. This was fixed on a tripod stand, available as part of a microphone stand. We only had to fix castor wheels under it for easy movement. However, when fitted, the weight of the colposcope head appeared to be too much for the stand, and it could not keep its vertical position fixed. An easy solution was obtained by adding some extra elastic rubber bands in parallel with the springs which provided a perfect manoeuvre. A picture of the finished device is shown in Figure 7.

The prototype was used to obtain an image in real life from a subject using white light only and it is reproduced in Figure 8 in grayscale. It has to be seen in colour to appreciate the quality. The picture is very clear, with the blood vessels clearly seen even in white light, due to the high quality of optics used in the binocular and in the webcam. This picture was taken without a vinegar wash, typically done for taking images in clinical practice.

With standard software nowadays available, it is possible to obtain different hues of a digital image, therefore, it appears that the green light in the hardware can be avoided. With a recent global search, a small monocular telescope was sourced which can focus down to 25 cm in its standard fittings. Although the optics appear to be of a slightly lower quality it may be adequate for clinical applications. A few samples have been procured to test its suitability.

2.3 Digital 12 lead diagnostic ECG

The ECG circuitry was developed from scratch. It was quite a challenge; the long experience of the group in developing bioelectrical equipment proved very useful [2]. As mentioned before, overall information about the main amplifier circuitry is available widely, but the front end network and switching circuitry, which is rather complex, was not available from any open source. Therefore, basic scientific knowledge was used to design such a network which eventually came out successful. The ECG equipment was interfaced to a microcomputer through the USB port and it obtained necessary dc power from the computer through this link as well. A microcontroller was used to create the interface. Internally an isolated power supply for patient safety and for common mode noise reduction was made based on a toroidal isolation transformer, designed and made by the group. So no external battery or power source was needed. The microcontroller used has a built in 8 bit Analog to Digital converter which was adequate for the present purpose.

All necessary switching of the 12 leads was done under software control from the microcomputer using graphical user interface. Individual leads (12 in all) of ECG can be recorded randomly through mouse control, which automatically switches the necessary front end network and draws the signal...
at the appropriate window on the monitor. The signals are stored on command and sent over the internet for telemedicine. As the raw ECG data is sent as a text file, the volume of data is very small and the ECG signals can be seen by a doctor at an expert centre in real time using appropriate software. All necessary software was developed by us.

At the front end we have also incorporated spike and surge suppression circuitry in order to provide defibrillator protection, and used high value resistors to limit dc currents to safe levels in case a fault causes the low voltage dc (5V) to appear at the patient leads. Thus the developed ECG equipment has all the necessary safety aspects taken care of.

The ECG equipment developed by us was evaluated by doctors at the National Institute for Cardiovascular Diseases on several patients with different types of cardiac problems. The signals produced by our equipment were compared with that using standard commercial equipment on the same patients, and based on the good agreement our equipment received their approval.

The main equipment has been built into a black acrylic plastic box with a footprint of about 13cm x 18cm and a height of about 8cm as can be seen in Figure 9. We have used commercially available patient leads, cables and electrodes at present. However, we have plans to make these locally when the cost will come down further. ECG signals taken using this equipment and displayed on a monitor are shown in Figure 10. The display has a graphical user input. So all controls are done through mouse selection and clicking.

3 Discussion

Unlike the industrially developed countries, rural population in the Third World makes a majority in these countries, and forms the majority of the global population too. Due to the persistent economic and social problems in the Third World presence of specialist doctors in the rural health centres cannot be expected within a foreseeable future. Telemedicine using Microcomputer, mobile telephones and the internet offers a possible solution to this problem as the price for these equipment and the services have come down in cost significantly in recent times due to large scale use. However, this would still remain severely limited if modern healthcare equipment, particularly of diagnostic nature, do not become integral parts of such telemedicine systems. Taking the present scenario where most of such equipment are developed and manufactured in a few industrially developed countries, coupled with the disparity in income between the country of the manufacture and the Third World, it is easy to deduce that this attractive facility offered by the modern technology will again remain severely limited. Because of the prohibitive cost of medical equipment and the difficulty in maintenance and repair in a remote country, the sufferings to a majority of the global population will continue unless the model proposed by us that all the necessary medical equipment are developed in each country through indigenous R&D and subsequent manufacture is pursued globally.

The effort of our group is an effort towards this model. If we can succeed, then it would be an example for other Third World countries too.

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References
