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Project factsheet information

Project title	Development of mobile phone based telemedicine with interfaced diagnostic equipment for essential healthcare in rural areas of Low Resource Countries
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Dates covered by this report	15 – 05–2015 / 30 – 06 – 2016
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Country where project was implemented	Bangladesh
Project leader name	K Siddique-e Rabbani <rabbani@du.ac.bd>
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Partner organizations	None
Total budget approved	AUD 30,000
Project summary	In low resource countries qualified doctors for medical care is not available to the majority of the people who lives in rural areas. Telemedicine offers an acceptable solution to this problem. Previous to the ISIF Asia grant, our organization developed and tested on the field a PC based telemedicine system with several diagnostic devices like Stethoscope, ECG machine, spirometer, etc., integrated into it, offering affordability and sustained use ensuring local maintenance and repair. This project aimed at converting that whole system into a mobile phone based platform so that the service can be taken to the homes of people through rural health workers with all essential diagnostic devices connected to the internet through smartphones. The following devices were targeted for development: Stethoscope, ECG, Respiration monitor, Thermometer, Blood SpO2, Tele Palpation and Remote Blood Pressure monitoring. The basic technology for the main platform, software for the user interface (both health operator and doctor) and three devices – stethoscope, ECG and lungs/respiration monitor has been developed. This will form the basis on which a commercial prototype may be designed if the needed financial support is available. The project has also given us some lessons in terms of teamwork which will be useful in future.

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Background and Justification

Almost 70% of the 160 million Bangladeshi people lives in villages and are far away from any hospital with qualified doctors. Although the national average for the number of doctors is about 4 per 10,000 people, this grossly misrepresents the situation in the villages where the figure is nothing but a ‘zero’. The Government has set up about 450 Semi-rural hospitals to serve the rural people but has found it very difficult to retain doctors there; only a fraction of the total posts are actually filled up at any time. Lack of civic amenities in those semi-rural areas are mostly responsible for this situation and most doctors prefer to remain in towns or cities. Therefore, unless there is an emergency, the rural people, particularly women, children, the infirm and the old mostly go without treatment. What they need most is primary and secondary level healthcare. In fact many complicated health situations and emergencies may be averted if medical attention is sought early. These people mostly go to local pharmacists, quacks or village practitioners for consultation which often leads to maltreatment leading to further complications, even causing death or disabling the patient permanently. The time, cost and hardship that the patient and the family has to go through can easily be guessed; the whole family is ruined in some cases. Besides, misuse of drugs like antibiotics and steroids are also very common through such treatment. The same is true for almost all low resource countries (LRC) of the world, home to about 80% of the World’s population.

Given the socio-economic situation in Bangladesh and the other LRCs we may not be able to create a situation in the near future when a qualified doctor will be easily available to all people in the rural areas. Therefore, telemedicine seems to be the answer.

However, telemedicine needs modern technological inputs which unfortunately has remained within the control of commercial manufacturers in the rich industrially developed countries (IDC) of the world for various factors. Solutions to telemedicine coming from these manufacturers in the IDCs will not be very useful to the LRCs because of the following.

1. Telemedicine in the IDCs are mainly geared to tertiary care, for patients in hospitals, for obtaining consultation from specialist doctors. Therefore, the system and equipment are all geared to such applications only and are not generally suitable for primary and secondary healthcare needed in the telemedicine systems in the LRCs.
2. Some telemedicine systems currently been tried in some LRCs again cater for complex diseases, with consultation of specialist doctors located in a foreign IDC. This needs a local doctor who essentially takes consultation of a specialist doctor abroad. A rural patient in an LRC cannot directly communicate with a foreign doctor, language and culture being strong obstacles.
3. For a largescale deployment of telemedicine in the LRCs either we need rural telemedicine centres where patients can come for consulting a doctor located in a town of the same country or we need roving health workers with a portable telemedicine unit through which a patient can consult a doctor directly from home. Besides saving travel and waiting time and cost of a patient, the latter is very useful for the women of the house for whom going out of the home for a considerable time is very difficult while it is also useful for children, the infirm and the old for whom the travel to a centre or a hospital is difficult. It is obvious, to make this happen we need tens of thousands of telemedicine related devices in a single country. The cost, maintenance and repair needs to be taken care of properly to continue the service without interruptions.
4. Even for some systems from the IDCs that may be applied to the LRC situation, the cost is very high because of the huge economic gap existing between the economies.
5. There is a lack of expert technical manpower in the LRCs who can maintain and repair the equipment coming from the IDCs. Therefore, once a device becomes out of order, mostly it never gets repaired, and the service stops.

6. Most of the modern medical equipment uses technologies that are kept secret and the devices cannot be repaired even if technically skilled personnel are available. Besides, many spares are proprietary and cannot be procured from the local market, which makes repair difficult and expensive.
7. Even if the initial procurement of such equipment is achieved through donation programmes, currently in vogue, these equipment mostly do not survive long under the extremes of weather and power line abnormalities existing in the LRCs. It has been reported by various donor agencies that about 70% of all donated equipment lies unused in the hospitals of the LRCs either because they are not functioning or are not appropriate for the target nation. Since it is hard to accept throwing away such expensive items, these useless equipment occupy and waste valuable physical space in the hospitals too. This is the situation in the big hospitals of LRCs with the most of technical and clinical manpower available to the respective country. For telemedicine, we need thousands of devices to be deployed to villages where even such technical manpower and facilities are not available. So one can understand that telemedicine with imported technology in the LRCs is going to be a huge failure.
8. The telemedicine system needs a user interface which links a patient with a doctor through video conference facility. The patient registration and management software and the prescription generation software should therefore be adapted to local language culture and conditions. A system developed in an IDC mostly suffers from a difficulty related to these situations. Even if the language is translated, the approach taken in the data that are acquired prior to the consultation and that given in the prescriptions need to take care of the other factors. This is not possible if a system developed in an IDC is directly employed in a LRC.

Therefore, if we really feel for the common people in the LRCs and do some real good to them, we need to the rethink the whole approach currently in vogue in the IDCs. What we feel at the Department of Biomedical Physics & Technology (BMPT) at the University of Dhaka in Bangladesh is that the only solution will come when the technology needed is developed indigenously in every country. In fact there are capable scientists and engineers in almost every country even if it is an LRC. Usually they are only used to install and maintain foreign made equipment and are trained so. However, they can easily be trained to design and develop essential medical devices. Again, BMPT feels that the current practice of patenting goes against such spread of technology that can take the benefits of modern technology to the global people. We frequently present the observation that 'ECG' and X-ray machines were invented more than 100 years back, still almost 80% of global population do not get the benefits of these two devices – and the current practice of patenting is a major factor behind this unfortunate scenario. Therefore, the medical equipment developer group at BMPT, which initiated its activities towards this aim in 1978, has several innovations to date but has not taken any patents against these products. It has taken a policy of not taking out patents for essential medical technology that it develops. Rather, it plans to teach scientists and engineers from LRCs in the basics of such designs so that they can make the devices in their own countries through appropriate adaptations. When such indigenous capabilities grow, the people themselves can design and develop and manufacture other medical equipment that they need.

A popular saying is that 'if you want to feed a hungry population for a long time, teach them how to grow food'. Unfortunately, it is surprising why no one thinks in the same line for essential medical devices. The only way out being thought of is 'donation of medical devices' which has not been successful as mentioned earlier. May be it is the 'selfishness' which the modern world thinks as a basis for motivation and growth, and we need to seriously think if this philosophy itself is tenable in the long run. Apparently it is not working, and we feel, here lies the crux of the problem the whole world is facing. We feel the same human being who is 'selfish' has an equally 'selfless' mind. Which of these will dominate will depend on the environment that we create. The aftermath of the 'selfish' philosophy is appearing very clearly and often very brutally in the present world. Had we cared for all the people and thought of going up together rather than in isolated islands, possibly the world could have been different. In fact 'technology' is at the centre of all disparity that we see today. Technology disparity has given rise to the huge economic disparity which in turn has given rise to all the global crises and conflicts that we are experiencing today. Unless we think of this deeply, unless we make technology for human enhancement available to all the people in the globe, no one can live in peace, even one creates a whole lot of barriers around oneself. A translation of a line from a great Bengali poet, Rabindranath Tagore, a Nobel Laureate, is of relevance here, '***You will have to equal in disgrace and humility to those whom you have humbled'.***

Coming back to telemedicine, the above philosophy has contributed to all our efforts at BMPT and therefore, we feel that the essential technology has to be developed indigenously in each country. With the background of technical expertise that we have and the experience of developing a PC based telemedicine system earlier with a few diagnostic devices, we embarked upon this conversion to a mobile phone based system and further expansion of our telemedicine technology with a generous grant from ISIF-Asia in 2015. We had set out an ambitious plan, keeping in mind that not all can be achieved within a span of one year, but we have developed the basic and essential technological elements that will make the next scaling up to a commercially deliverable system easier. This final report of the one year project presents the achievements of this period with a brief introduction of the earlier work and a plan for the immediate future.

The Department of Biomedical Physics & Technology of Dhaka University (BMPT), under the leadership of the Project Leader had earlier developed a PC based telemedicine system with several diagnostic equipment like Stethoscope, ECG, Microscope, X-ray Viewbox, Colposcope, etc., integrated into the system at low cost. These equipment are either designed and made by the group locally, or improvised from other types of available instruments. Coupled with standard audio-visual medium these instruments have enhanced the capability of telemedicine for primary healthcare. This PC based telemedicine system has already been taken to the field and has shown signs of success. We are also developing the following diagnostic equipment for interfacing to the PC: i) Ultrasound Foetal Doppler, ii) Tele-palpation, iii) Tele-blood pressure measurement (the doctor at city will listen to sound form a stethoscope in real time and will get the pressure information of a blood pressure cuff applied on a rural patient, both in real time to measure the blood pressure remotely), iv) blood glucose monitoring, v) SpO2 monitoring. We are also planning to link weighing scales and thermometers to the PC for direct data acquisition. Development of suitable diagnostic equipment for telemedicine is a continuous process, the list will keep growing with continuous R&D activities.

The Bangladesh healthcare system also has roving rural health workers who call people at door to door. Therefore, it would be useful if we could develop a mobile phone based Telemedicine system with some essential diagnostic instruments integrated to it. Besides, many of the city doctors spend considerable time in their cars because of the heavy jam in the city traffic. So, if the consultation is available through mobile phones, these doctors could carry on the consultation during such travel, making a good use of the time. Besides, they could also use the mobile phone at home or at work to cater to emergency consultations. The present project has been taken up to address this very solution, development of a telemedicine system including some diagnostic equipment using mobile phones and or Tablet PC, preferably based on Android operating system.

Project Narrative

Earlier development:

1. ***Electronic Stethoscope:***

We took a conventional acoustic stethoscope, cut the rubber tube to remove the earpieces and fixed a microphone insert (electret microphone) into the tube at this end. Thus it gave an electrical output when appropriately connected to a PC through its microphone input jack (Figure 1). Initially we tried sending audio signals through Skype and Google Talk. These commercial solutions are optimised for voice communication and filter out low and high frequencies. However, we need very low frequency audio signals for a good quality rendition of heart sounds. Therefore, neither of the above satisfied our purpose, so we went for a compromise solution using the concept of 'store and forward'. The doctor instructs the health operator to hold the stethoscope-head at suitable locations on the patient's body and show it on Skype video. In this way the doctor can see visually if the placement is correct and listens to get a feeling for the sound. When satisfied the doctor asks the operator to record 5 to 8 seconds of sound using a free audio software package known as 'Audacity'. As soon as the recording is finished, the operator saves the file and sends it to the doctor through Skype. The doctor then plays this file using 'Audacity' in her/his computer and gets a reasonably good reproduction including low frequency heart sounds. This 'store and forward' method is being used in our existing telemedicine programme and the doctors seems to be satisfied with the technique and performance.

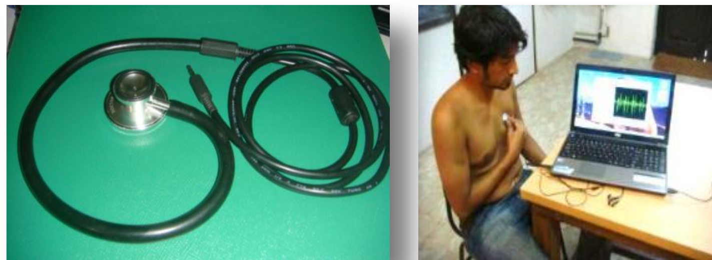

Fig.1: Improvised electronic stethoscope

2. ***PC based ECG equipment:***

This equipment, designed from scratch by our group, connects to a PC through its USB port (Figure 2). It also takes power from the host PC and no external power is necessary. It has one channel

Fig.2: Our PC based ECG equipment and its data acquisition interface

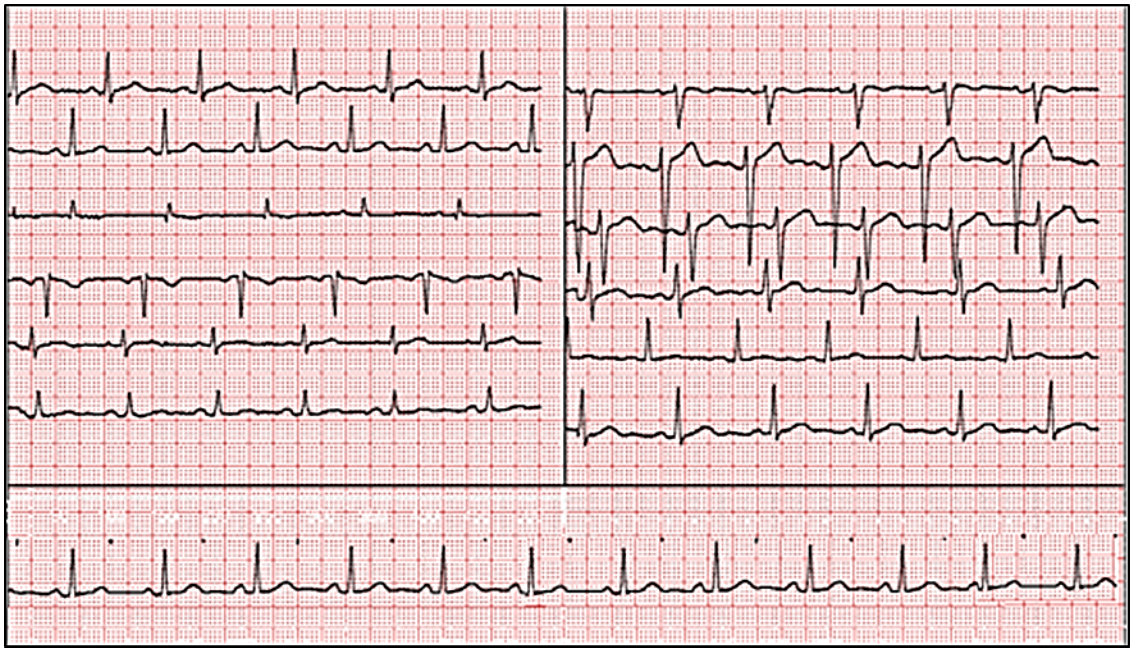

Fig.3: Combined 12 lead ECG trace as sent to a doctor

and acquires standard 12 lead ECG data sequentially through mouse click control of the operator. It also displays the ECG traces on the host PC, stores data in local hard drive and transmits data through internet in 4 second packets. At the receiving end, a doctor can see the ECG traces almost in real time (delayed by about 4 seconds) using the same software. The combined 12 lead ECG data (Figure 3) is also displayed and sent to a doctor as an XML file (about 150 KB size) in which case the doctor has to have our software to read and display the file. Alternatively the whole trace can be saved and sent as a pdf file (about 4MB size), which the doctor can see using common software usually available in all PCs and smartphones. Of course the file size is much larger and it takes longer to transmit.

3. *PC based Respiration Monitor:*

Respiration rate measurement is very important in the diagnosis of Pneumonia, particularly for children. Fixing of any existing sensor for respiration monitoring makes a baby perturbed, and he/she starts crying. This changes the respiration rate, making the measurement useless. We used one of our innovations – 'Focused Impedance Method (FIM)' that uses four electrodes (plus a common electrode) and an innovative design of flexible palm wearable electrode as a solution (Figure 4). The mother of the child wears the flexible electrode pad in her palm and places it on the thorax of the baby/child when the respiration cycle is instantly

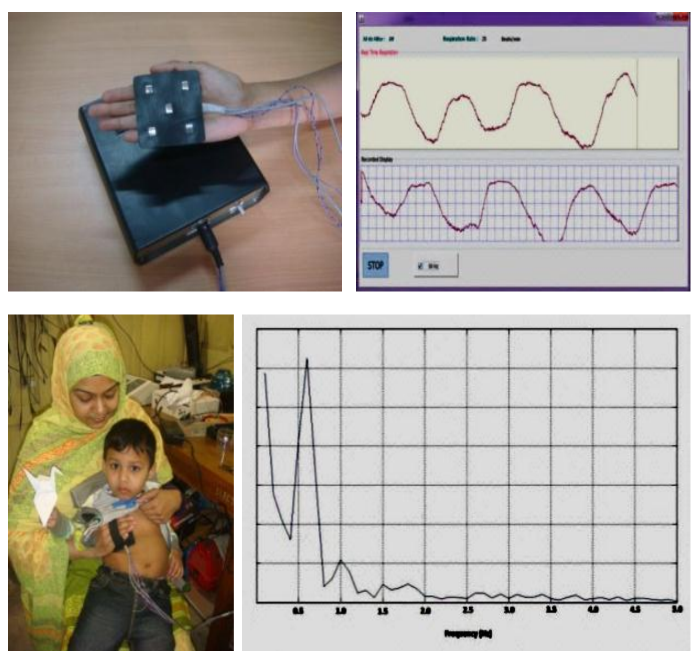

Fig.4: Electrical Impedance based respiration and localized lungs ventilation monitor. Special probe for children.

monitored through a PC based data acquisition system. The system may be used not only to monitor the respiration rate, but to monitor regional changes in lungs ventilation (air movement) as well making it useful in the detection of oedema (fluid accumulation) or masses in the lungs. The technique may also be useful for adults in the detection of above conditions using normal electrodes.

4. Digital Microscope:

A good quality webcam (Carl Zeiss glass lens, 2MP, 30frames per second video) was used to convert an ordinary microscope to a digital one (Figure 5). The final quality obviously depends on the quality of the microscope as well. Both still and video images can be obtained, data for which can be transmitted over internet for telemedicine. In many rural areas pathological technicians are available but not qualified Pathologists. Therefore, this digital microscope could be helpful in providing services to the rural population. This device can also be used to teach many students using a multimedia projector.

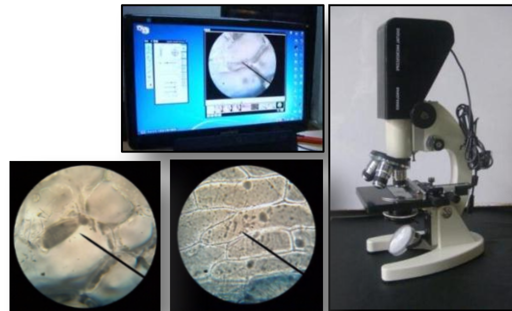

Fig.5: Improvised digital microscope

5. Digital X-Ray View-box:

In Bangladesh many film based X-ray machines available, even in rural hospitals. However, radiologists who can clinically interpret the images are not available in rural areas. Therefore, sending images over internet could be helpful in Telemedicine. The same webcam used for the microscope was mounted on a stand. A view-box was made to hold the X-ray films. Thus it produces a digital image of an X-ray film image for storage and transmission through internet (Figure 6).

Fig.6: Improvised digital X-ray viewbox

6. Multipurpose Digital Imaging device:

This is again the same webcam mounted on a flexible stand (Figure 7). This may be used to photograph skin in Dermatological conditions, of teeth in dental conditions, and of the whole face of a patient if it is required. The image, in digitised form can then be sent to a doctor over internet. It may also be used to copy written documents or prescriptions. Using a conventional vertically mounted X-Ray View-box, this device can also be used to take photographs of X-ray films, so that a separate X-ray view-box as mentioned above is not necessary. If someone has an ultrasound scanning machine, this camera can be used to photograph the image from the monitor and send the data to a doctor over internet.

Fig.7: Imaging device

As mentioned before, the idea is to develop a mobile phone based Telemedicine system with some essential diagnostic instruments integrated to it so that a roving rural health worker (RHW) can provide a doctor's consultation to patients right at their homes. The whole system should fit within a large brief case like box which an RHW will carry and visit people at their homesteads. The RHW will register a patient, issue an identification number and store necessary personal information which will be available in future. For any desired consultation with a doctor, the RHW will take some standard measurements like height, weight, temperature, blood pressure etc., of the patient which will be sent to a doctor through a web server (cloud) through a mobile phone (smartphone) or a Tablet PC. The RHW will also link up the doctor through Skype or any video conferencing software so that a two way communication can take place between the doctor and the patient. If the doctor wants to listen to stethoscopic sounds of the patient the RHW will place the chestpiece of our Tele-Stethoscope on the patient following the doctor's instructions and the doctor will either listen to the sound in real time or a few seconds of recorded sound. The latter will give a better quality sound reproduction, which is particularly needed for heart sounds. If the doctor wants to get information on the softness or hardness or tenderness of an organ that is just under the skin surface (such as liver, abdomen, etc., which a doctor usually feels using fingers) the Tele-Palpation instrument innovated by us will be used. This is a completely new concept in telemedicine and our development has almost reached a stage where it may be put to clinical trial. If the doctor feels it necessary the RHW will connect our Tele-ECG machine to the patient and send the 12 channel ECG traces to the doctor in almost real time (only 4 sec delay), one channel after the other. If the doctor sees that the trace for a particular channel is not right, he or she can ask the RHW to repeat that channel and get a correct recording. Similarly other diagnostic equipment, as and when developed, will be added to the system enhancing the dimensions of the Telemedicine facility. Finally, the doctor will generate and prepare a prescription which will be sent to the RHW immediately so that she can print it out for the patient. A data base of symptoms, advices, medicines, etc., will help the doctor in the preparation of the prescription. The doctor may also ask for further investigation or may refer the patient to a hospital or a specialist doctor and come back with the reports later.

The present project has been taken up to address this very solution, development of a telemedicine system including some diagnostic equipment using mobile phones and or Tablet PC, preferably based on Android operating system.

For the doctor, he or she can give the consultation using a PC Tablet or a mobile phone, either from home or office. Many city doctors spend considerable time in their cars because of heavy jam in the city traffic. If they have a chauffeur driven car they can easily use the time to give consultation using a tablet PC or a mobile phone utilizing the time.

The objectives initially mentioned in the project proposal involved the development of a mobile phone based telemedicine system with some integrated diagnostic devices which was expected to include the following:

i. Stethoscope (for live or semi live transmission of body sounds)
ii. ECG (12 lead, for real time and/or store & forward transmission)
iii. Respiration monitor (for real time/semi real time transmission)
iv. Thermometer
v. Blood SpO2 (if possible)
vi. Tele Palpation (rudimentary information to mimic the sense of pressure felt by a doctor)
vii. Remote Blood Pressure monitoring (both the cuff pressure and the K-sound from stethoscope to be conveyed to doctor in real time to enable the doctor to take readings for measurement of blood pressure him/herself)

The system operates around a main platform which links all the above diagnostic devices and sends the data to a mobile phone or a Tablet PC, based on Android operating system. The mobile phone sends the data to a web server (cloud) which is also accessed by the remote doctor who gives the consultation.

It is obvious that the objectives are rather ambitious for a limited time span of only one year. However, the idea was that if the main platform and the mobile phone link between the RHW and the doctor can be developed the rest can be added one by one.

We partnered with other organisations for field trial of our PC based telemedicine system developed earlier and the experience gained was useful in the planning and designing the present project. This field trial gave us first hand feedback from the ultimate beneficiaries, the poor people in the rural areas. The main partner organisation is the '*Access to Information'* programme of the Bangladesh Prime Minister's Office. It is a programme jointly funded by the Bangladesh Government, USAID and UNDP. The office of the Directorate General of Health of Bangladesh Government has given us permission to run Telemedicine service centres throughout Bangladesh subject to certain terms and conditions. Of late the Dhaka University Administration has recognised our efforts and has allowed us to name the activity as *'Dhaka University Telemedicine Project'*. We hope that all these recognitions will allow us get the confidence of the general people.

Of course the present project granted by ISIF-Asia does not involve any implementation – it only is directed to the development of technology. However, the presence of our PC based system in the field may help us in some trial implementation of this new technology in the near future.

Again, being an innovative project, some items posed problems that were not envisaged before. Such a thing happened with the development of the stethoscope for telemedicine. We used a condenser microphone to convert the acoustic signals into electrical signals which then was fed to a USB sound card, with built in pre-amplification of the microphone signal. However, a stethoscope requires the transmission of particularly low frequency audio (bass, starting from 20Hz) to transmit heart sounds. Skype, which is normally used for video conference between a patient and a doctor though internet, does not allow such low frequencies to pass. Besides, any internet transmission has an inherent time delay, which again may vary with time. Information on the regularity of heart beats would be lost because of this. For this reason we turned to mobile phones which has very negligible delay in transmission. However, mobile phone networks also do not cover low frequencies needed for heart sound transmission. Therefore, it was thought that a frequency modulated audio signal will solve the problem. Considerable effort was given to design and develop electronic circuitry to do this job. The processes worked well independently, but when a combination was tested using transmission between two mobile phones, things were not as expected; distortions and noise were introduced that were found to be very difficult to resolve. Finally, we abandoned the effort for real life transmission of sound for heart sounds, rather a 'store and forward' method was adopted. In this arrangement the sound would be recorded for a few seconds in the tablet PC or a mobile phone and the file would be transferred through the web server. The doctor on the other end would retrieve the file and listen to the recorded sound. On a PC, use of a free audio software named 'Audacity' gave a good quality recording and retrieval, reproducing the heart sounds well. Listening to heart sounds using an acoustic stethoscope and using this device (with recorded sound heard using a reasonably good quality headphone) the reproduced sound appeared similar. Lungs sound were also heard with an acceptable quality.

We ended up developing two versions of the stethoscope – one that converts a commercial acoustic chestpiece to give an electrical output through a microphone while the other was made out of a small drinking cup made of plastic. The former connected a PC through a USB sound card. In the second model all the electronic circuitry including a rechargeable battery is built within the plastic cup. Using a headphone the stethoscopic sound can be heard directly making it an electronic stethoscope. Through a two way jack its output can be connected to a PC as well.

Again the Tele-Palpation unit that we have developed is a world's first as no one has thought of a similar device for telemedicine before. This will give a doctor some information that is usually obtained through pressing onto specific regions of the body of a patient by hand. There was some doubt about its success initially, however, after developing two prototypes, as described in the Annexure, we feel confident that this new device is going to be a success bringing a significant improvement in Telemedicine globally.

The main platform was a critical part of the system and needed quite a bit of thinking and planning to make it flexible enough and adaptable to future enhancements of the system. We decided in favour of a WiFi communication with the mobile phone and not a blue tooth because of this reason. The main platform has 8 free slots to take in 8 different sensors or diagnostic devices.

During this period we could develop the basic technologies of most of the challenging segments of the system. These are: i) the main platform, ii) thermometer, iii) Stethoscope, iV) Lungs/Respiration monitor, v) 12 lead ECG (one channel, sequential), vI) Tele-Palpation, vii) Software for mobile phone based patient registration, doctor consultation and prescription generation. The others that were not finished are: i) SpO2 monitor and ii) Remote blood pressure measurement because two team members moved to other jobs within the period. However, these items can be completed later. We are also communicating with a group in Newcastle University in UK who has claimed to have made an under $50 device which in conjunction with a software can give ultrasound B-scan. We plan to incorporate such a system to our telemedicine as well. If one sees the details given in the annexure, one would feel that the amount of development done in such a short time span of one year is indeed remarkable.

As the basic technology is ready, a scale up of the project is being planned so that the system may be taken to commercialisation.

Current Development

The main idea of the present work was to develop a mobile phone based Telemedicine system, instead of the PC based solution developed earlier by us. Since the idea is to provide health services at the doorsteps of the patients through a Telemedicine Health Operator (THO), there is also an issue of portability, i.e., compactness, size and weight.

The main platform

The idea is to have a main platform of circuitry containing the microcontroller, data acquisition and network communication circuitry, preferably wireless, to connect to a mobile phone or a tablet PC. There should be sockets in this main platform to mount and connect individual diagnostic circuitry for the essential diagnostic devices. The whole thing would be housed in a portable box that can be carried to homes of individual patients by a THO. Using this box the THO can send data to the web server and connect to the doctor for video consultation and receive prescriptions from the doctor in turn.

Software for web hosting of all the information, continuous storage and retrieval by authorized individuals, user interfaces for patient registration and information entry from the THO's end using a mobile phone or a tablet PC and that for prescription generation from the Doctor's end were also to be developed.

Firstly, the diagnostic items that would go into the main platform were planned as follows.

a. Thermometer
b. Stethoscope (with low frequency sound capability)
c. Respiration monitor (electrical impedance based)
d. Diagnostic ECG (12 lead)
e. SpO2 monitoring
f. Ultrasound Foetal Doppler
g. Tele-palpation
h. Remote measurement of blood pressure

Besides, there would be some measurements like height, weight, temperature, etc., that the THO would perform manually and enter the data by typing into the keyboard. Of course we will continue expanding the measurement capabilities through development of appropriate hardware. In this first year of work we have developed the basic technologies for most of the above, the main challenges has been tackled. Now it needs to be converted to a commercially manufactured product. Although all the elements are not yet been developed, the software has the ability to cater to the need for adding the components as and when they are developed.

System overview:

Under the present project the solution has been designed with the following scenario, depicted in Figure 8.

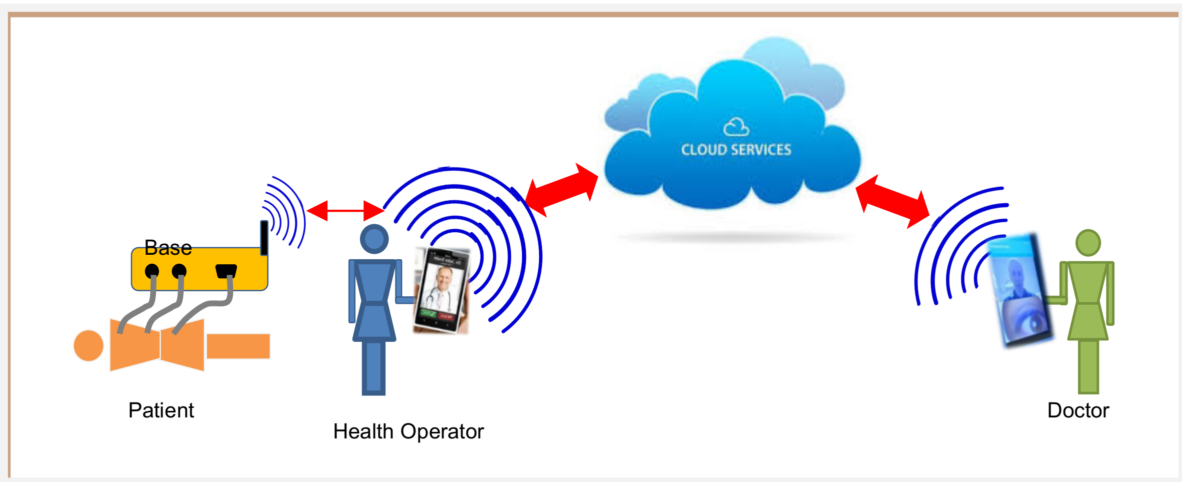

Fig.8: Proposed mobile phone based Telemedicine system

A Telemedicine Health Operator (THO), mostly a lady, carries a briefcase sized box (similar to the one shown in Figure 9), the base unit, containing all the necessary diagnostic devices that are coupled to a hand held tablet PC or Smart phone through a wireless link. She connects to our telemedicine web server (Cloud Services), enters patient data if it is a new patient, or retrieves patient data if old, and enters or updates relevant information. Some simple measurements like height, weight, etc., are measured using conventional devices and data entered manually. She then connects to a doctor of the telemedicine system who is online at that time, the link being established through our web server. The THO puts the patient on a video conference with the doctor and starts the consulting process. If needed, the THO will place a stethoscope at locations on the patient's body as instructed by the doctor while the doctor will ask the patient to perform certain physical manoeuvres. The doctor will hear the sound in real time, but it may not be always of the highest quality. In that case the health worker will record the sound for a few seconds using appropriate software and will send the recorded data to the doctor through the web server. If the doctor wants to find the quality of lung ventilation at different locations, the THO will place our innovative Focused electrical Impedance based lung function monitor at the chosen points and the doctor will see the output graphs and numbers in almost real time. If the doctor asks for an ECG of the patient, the THO will connect electrodes to the patient appropriately and acquire 12 lead ECG data; the doctor will be able to see it in almost real time. If needed, the doctor will send the composite ECG traces to a cardiologist through the web server or through email for proper diagnosis. The THO can use the camera on the mobile phone to take pictures of specific locations of the skin if there is a skin problem and send it to the doctor as well. If the patient has an X-ray film taken at a rural clinic or hospital where there are no radiologists to interpret the image, its image may be acquired using the camera and sent to a radiologist, again

Fig.9: A large briefcase like box that a THO will carry with all the telemedicine equipment inside

through the web server or through email. With more functions added in the future, the possibilities are endless.

The system was planned as follows, and depicted in Figure 10 schematically. There would be a Main platform circuitry to which all the diagnostic devices will be connected in a modular manner. This base will have a built in WiFi unit through which it will connect to the mobile phone (smartphone) or tablet PC carried by the THO through an Application Programming Interface (API). Thus this base unit will act as a web server through which the mobile phone will communicate to any of the connected diagnostic devices. Designing different APIs, this will in

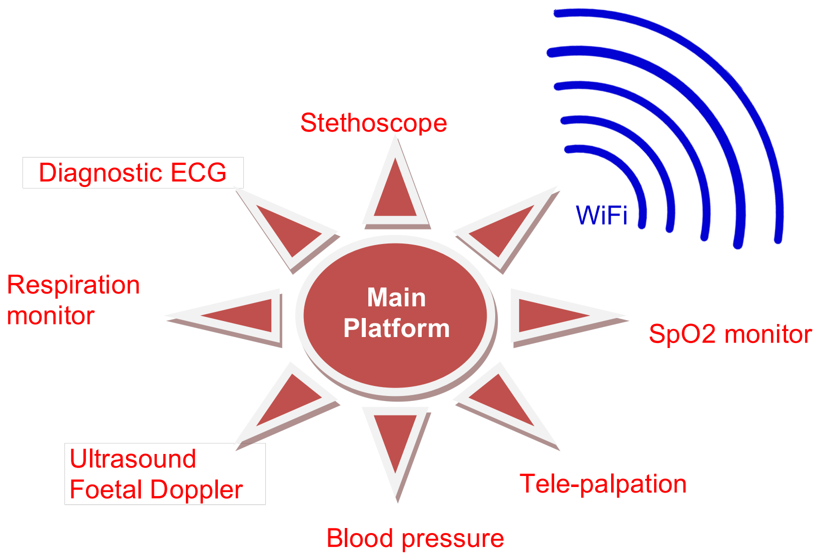

Fig.10: The system overview at the Health Operator end.

fact allow connection to mobile phones or PCs running any operating system. The idea for choosing WiFi rather than Bluetooth link was that in course of time this unit may be able to communicate with the Web server in the ‘cloud’ directly without the intermediary of a mobile phone, going in line of the ‘Internet of Things (IOT)’ of the future. A rechargeable battery fixed on this platform will provide power to all the connected modules.

The THO will connect to the cloud web server using the mobile phone (Figure 8). However, we are planning the web server to be versatile so that it can handle inputs and outputs to any PC or mobile phone (Smartphone) irrespective of operating system. Besides, in future, we may want this telemedicine system to serve any individual patient from home. Therefore, the software for the webserver is to be developed accordingly.

The work has been separated into i) Hardware and ii) Software. The whole team met once every week with the project leader to discuss various issues. The hardware developments are described first below followed by development in the software area. The current status of development of the various elements and modules are described below.

a. **The main platform:** It is comprised of the microcontroller, data acquisition and wireless network communication circuitry to connect to a mobile phone or a tablet PC. It also has a power supply unit through a rechargeable battery and provides isolated power for some diagnostic circuitry. There are sockets in this main platform to mount and connect individual diagnostic circuitry for the essential diagnostic devices. The whole thing would be housed in the portable box shown in Figure 8. Using this main platform the THO can send data to the web server and connect to the doctor for video consultation and receive prescriptions from the doctor in turn. It has been designed to have appropriate sockets to connect to diagnostic modules as indicated above and is shown in the schematics and the photographs show in Figures 11 to 14.

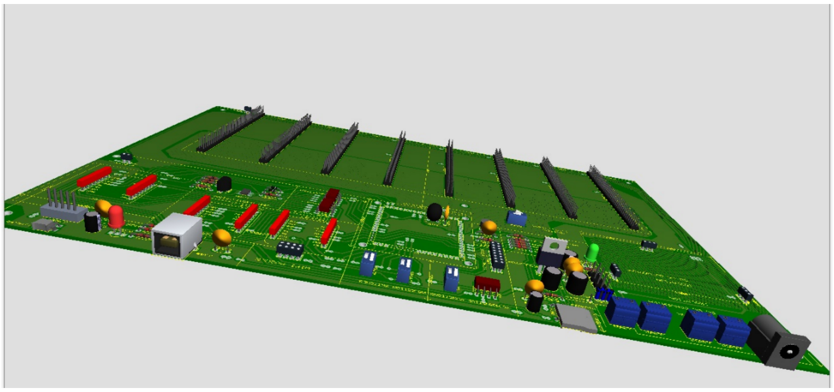

Fig. 11: Conceptualisation of the Main platform

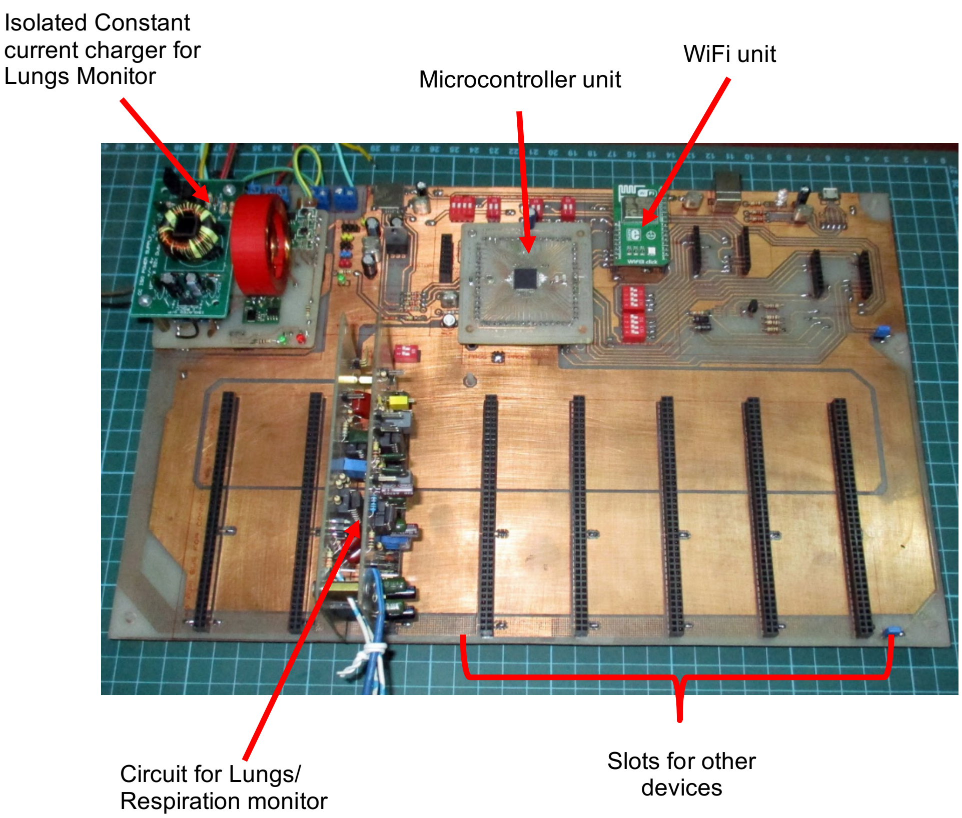

Fig. 12: Actual Implementation of the Main platform

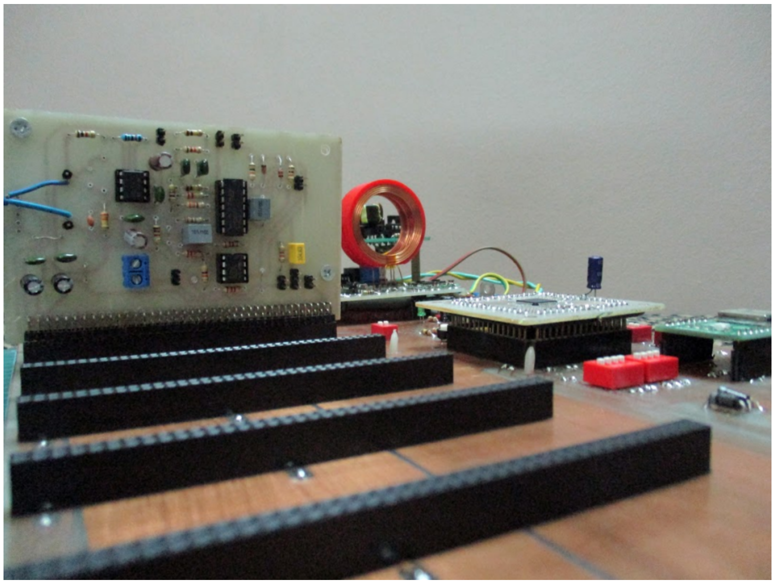

Fig. 13: Another view of the Main platform with a circuit inserted into a socket

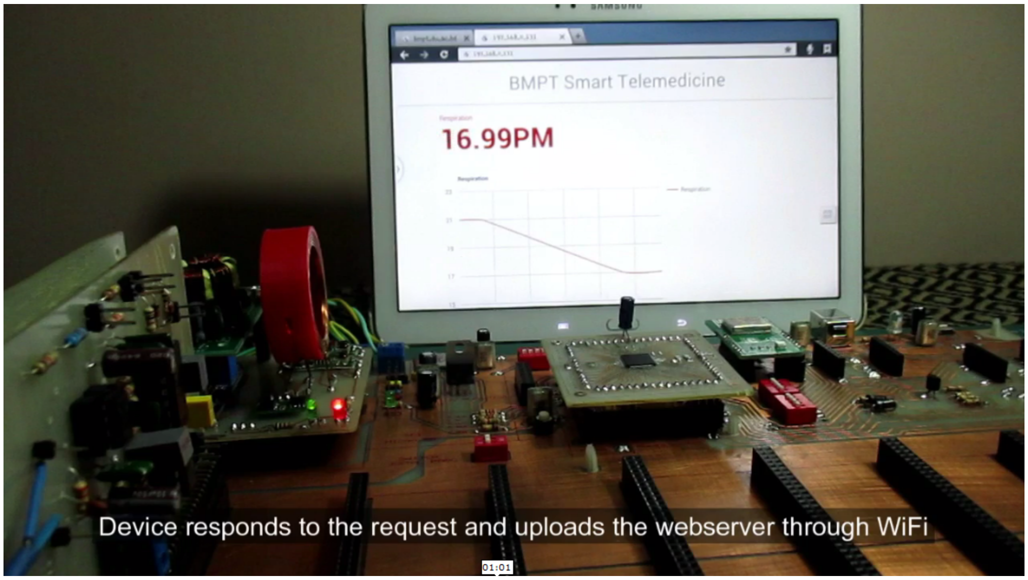

Fig. 14: The main platform connected to a Tablet PC through WiFi, showing data acquisition and graph plotting

A video showing the action of the main platform in acquiring analogue data (simulated respiration monitoring for the example shown) and transferring it to an Android Tablet PC through its WiFi capability and then plotting the graph is available at the following link:

https://vimeo.com/174762124

Specifications of the Main Platform:

1: Microcontroller Unit:

Microcontroller: dsPIC33EP256MU806IP

- DSC – digital signal controller
- 70 MIPS
- 16 bit modified Harvard architecture
- 10 bit ADC
- 24 analog channels
- Digital communication – USB, UART, SPI, I2C

MCU samples sensor data and sends it to the smart phone through WiFi. Communication between WiFi and MCU is established using UART @ 115200 BAUD rate

Power consumption with modules enabled: ~ 160mA – 180mA @70MIPS 3.3v

2: WiFi module:

We are experimenting with two different modules. ESP8266 and MRF24WB0MA. Current choice: MRF24WB0MA.

Manufacturer- Microchip

Standard – 2.4 GHz IEEE 802.11b

Protocol – TCP/IP with MCW1001 companion controller

Encryption – AES128

Current consumption – 154mA Tx [+10dB], 85mA Rx

MCU interface – UART

** we may update this chip to comply with IEE802.11 b/g/n [using MRF24WN0MA]

3. MicroSD card:

Memory slot: MicroSD card [8 GB] can be connected to the MCU using SPI [serial peripheral interfacing]. We can use it for data logging.

4. USB:

Connectors for both device and host. For future implementation [if needed].

5. Power supply:

- 3.7v 2000mAh Li-Ion Battery
- Onboard charging circuitry
- Isolation power 01 – for both digital and analog circuit
- Isolation power 02 – for constant current source of Respiration Rate Monitor

(5.1) Isolation power supply 01:

- +/- 5v supply using wireless inductive power transfer
- Max current [+5v] 470mA
- Max current [-5v] 220mA
- Short circuit protection
- Quiescent current ~ 62mA

- Efficiency ~ 64% @ 1.2W output load
- Separation between coils ~ 4mm

(5.2) Isolation power supply 02:

- +/- 4v supply switch mode with isolation transformer
- Max power 320mW
- Used for the constant current source circuitry of Respiration Rate Monitor

6. Bio-sensor slots:

- On board 8 slots [40pin bus]
- Separate power for Digital [3.3v] and Analog circuitry [+/- 5v]
- Communication features – SPI, UART, I2C
- Digital I/O – 14 [10 dedicated + 4]
- analog input

b. Stethoscope: A considerable time has gone into the design of this item. Initially it was decided to use the audio channel of the mobile phone as this gives a minimum time delay for transmission (internet is usually slower). However, a mobile phone network usually filters sound and allows a narrow bandwidth, approximately between 300Hz and 3.5 kHz, just to send intelligible voice sound. On the other hand a stethoscope needs to send signals approximately between 30 Hz and 1 kHz; heart sounds requiring the lower side of this frequency range. A solution was sought in the use of modulation and demodulation techniques, as used in radio transmission of audio sounds. An electronic circuit was designed and developed to modulate a carrier frequency of 2.5 kHz using low frequency audio signals. Similarly for the receiving end, a demodulation circuit was designed and developed to decipher the audio signal from the modulated carrier. Using low frequency audio signals from a laboratory signal generator and sending the signal through a mobile phone, a reasonable quality of transmission was obtained, although some noise got into the signal which could be filtered out. However, when the system was used to transmit real heart sounds picked up using our electronic version of the stethoscope, the sound quality was heavily distorted and some noise was introduced which were almost impossible to filter out, as they occupied the same energy band as the heart sounds. It may be possible that the heart sounds had a sharp rise which initiated some automatic signal processing in the mobile phone system that introduced the noise. After several failed attempts to obtain a good rendition of the heart sound on transmission this approach has been abandoned. Besides, we do not know what processing changes to signals will be brought in the future by mobile phone companies, therefore, it is best to be in control of the signals ourselves. The solution that we have come up is as follows.

The electrical output of the stethoscope is taken to a commercial USB sound card devices which has both audio input and output jacks. This has a provision for necessary biasing of typical condenser microphones and has a built in pre-amplifier. Using any audio software the sound is recorded (we found ‘Audacity’ a free software to be very useful).

The THO can monitor the sound when she places the stethoscope head on the patient’s body through connecting an earphone to either the output of the USB soundcard or the speaker jack of a PC. The recorded signal is sent as a file to the web server. The doctor at the other end can access this file and hear the sound playing suitable software. This is the ‘store and forward’ method.

To convert the sound to electrical signals we simply connected a condenser microphone insert to a normal stethoscope chestpiece through a rubber tube as shown in Figure 15(left). However, it caught surrounding noise which affected the quality. After a considerable experimentation we found out that if we put a thick sound insulation around the microphone the noise reduces significantly. This is shown in Figure 15(right). It has been tested for heart sounds and compares well with that heard using the acoustic equivalent.

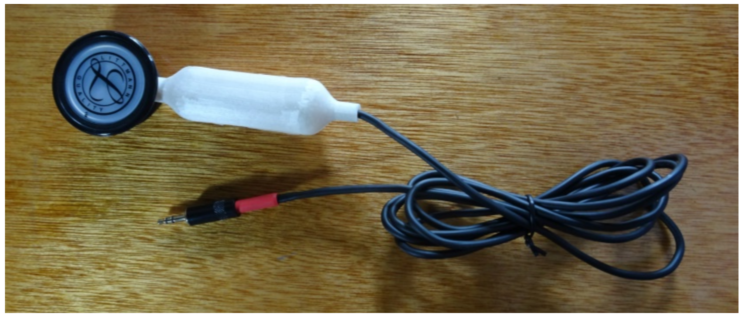

Fig. 15: Conversion of stethoscope sound to electricity using a microphone insert without sound insulation (left), with insulation (right)

Fig.16: Original pill box chestpiece (top left), practical prototype with all electronics and battery built-in (left), being used on a person (top)

Recently a new idea has been introduced that will reduce the cost of the stethoscope significantly. So far we have been using commercially available stethoscope chestpieces and the one giving a reasonable quality of heart sounds is sold at about US$70 in the local market. Using basic concepts of Physics, the project leader came up with idea of using a plastic box instead. The first attempt using a pill box came out very successful in delivering a good quality heart sound. Figure 16 (top left) shows the improvised pill box stethoscope chestpiece which was a proof of the idea. For the practical prototype, a hard plastic box (drinking glass, commercially purchased) has been used and all the electronic circuitry has been built into it including a battery so that this can also work as a stand-alone electronic stethoscope. Using a branched jack the output may be taken to both an earphone for local monitoring and to a PC or a Tablet PC or a Smartphone for online transmission of data. The other two pictures in Figure 16 show this prototype which gives a reasonable sound quality.

c. **Respiration and Lungs ventilation monitor** (electrical impedance based): As mentioned before, respiration rate measurement is very important in the diagnosis of Pneumonia, particularly for children. Lungs problem is also widespread among adults in Bangladesh. Therefore, a way of detecting

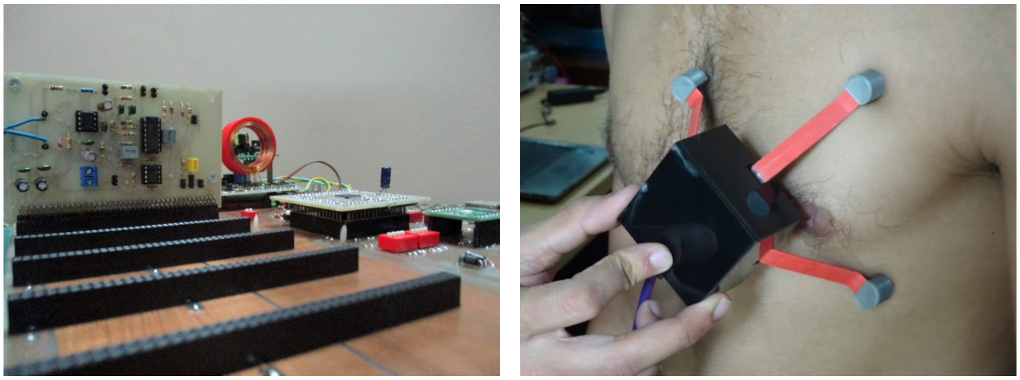

Fig.17: Left: Circuitry for Electrical Impedance based Respiration monitor mounted on the main platform. The electrode probe with detachable arms placed on a person.

ventilation in different segments of the lungs is necessary and as mentioned before we developed a system based on electrical impedance in our earlier work. In the present project we redesigned the whole circuitry to mount it on a socket on the main platform as shown inn Figure 17 (left). Fig 17 (right) shows an electrode probe being used on a person. It has detachable arms so that it can be used both on adults and children using different lengths of the arms. However, the palm worn electrode pad developed earlier and shown in Figure 4 will also be used with the same circuitry for measurement on children and babies so that they do not cry.

a. **Diagnostic ECG (12 lead) Device:** Since the envisaged mobile phone based unit will be battery powered (rechargeable), some isolation circuitry as used in our earlier PC based design may be taken out without causing any deterioration of the acquired signals. The earlier design got its power from the USB port of a PC. Here, this will get power from the common power supply available in the main platform. The existing circuitry has been redesigned for this purpose. The software interface is being appropriately developed for the small screen of a smartphone or a small tablet PC. Figure 18 shows the ECG system for a tablet PC (android based).

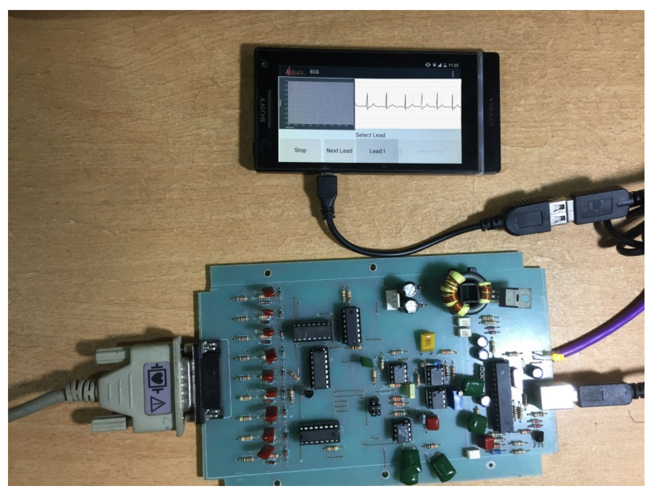

Fig.18: ECG circuit with Android based smartphone

b. **<u>SpO2 monitor:</u>** The earlier work done by us on this instrument was not extensive, just a preliminary one. SpO2 monitoring using non-invasive optical sensors are based on optical absorption spectrum of oxygenated haemoglobin and deoxygenated haemoglobin in blood. However, in the presence of other tissues in the optical path the technique to extract SpO2 of blood depends on empirical formulae and a few variations exist at present. From the hardware point of view, there are two techniques, using transmitted light and using reflected (scattered) light. We were inclined to use the reflective type as both the light source (LED) and the sensor are in the same block, it is easier to fabricate. We are studying these different approaches to come to a decision in order to obtain the best possible results within available resources. The item is yet to be developed. Small readymade modules are also available giving a digital value of the results. We are also contemplating of using such modules, reducing the development time.

c. **Ultrasound Foetal Doppler:** This basically uses ultrasound Doppler Effect to detect movement of heart chambers and valves of a foetus while inside the mother's womb. The challenge is to separate the signal from those of the surrounding structures in the mother's body. Such probes are available commercially, however, in order to reduce costs we plan to develop an indigenous one from the basics. Some preliminary work in fabricating an ultrasound probe using piezoelectric crystals have been done including some work on the essential electronic circuitry to extract any movement in the pathway of the ultrasound beam. Further work is necessary to make it into a usable device. We will work on this item later.

d. **Ultrasound Scanner:** This was not in our original objective, but, we thought of developing a low cost scanner after we get experienced with the Foetal Doppler system as an Ultrasound B scanner is very useful in diagnosis. For this, two options are being considered. One is to obtain a readymade wireless ultrasound probe from a Chinese manufacturer costing at around USD 1000, and the other is to obtain a new low cost system developed by a UK University (Newcastle) which uses a low cost rocking sensor (under US $50) and obtains the image through an appropriate software, which may be provided free if the said University agrees.

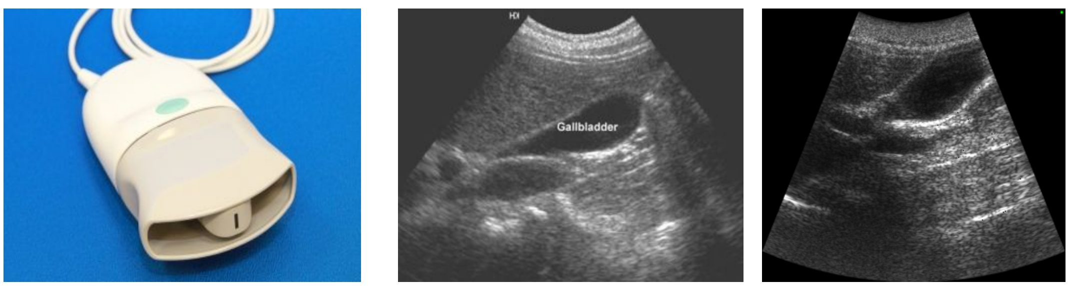

Fig. 19: The under $50 ultrasound probe developed by Newcastle University, UK (left). Image of a Gall bladder from a high-end scanner (middle) and that using the low cost probe (right)

Of course it has some limitations that it may not provide fast video images required for cardiac monitoring, but for many common applications in primary and secondary healthcare, this may be adequate. This item may need collaboration with the UK University for which we have initiated communications. Figure 19 shows a picture of this device and a comparison of its image with that obtained using a standard ultrasound scanner costing many times more.

e. **Tele-palpation:** This is a very new idea in Telemedicine, not attempted by others so far. Palpation, or sensing the stiffness or softness of a particular anatomical structure or organ of a patient gives important information to a doctor. In Telemedicine this is not possible; a severe limitation of the procedure. We tried to bridge the gap somehow, giving some useful information on palpation to the doctor. For this we are designing a device that will give both the amount of depression of a plunger with respect to the normal position of the surrounding skin surface and the amount of pressure applied. The remote doctor will guide an operator, through video conference, the locations on the patient's body where to apply the probes, and the resulting plunger depth and pressure values will be transmitted to the doctor in real time, displayed suitably on the monitor screen.

Conceptualising the device and its presentation to a remote doctor presented quite a bit of challenge as it is a completely new idea. After trying several models we developed one that appeared to be suitable and two

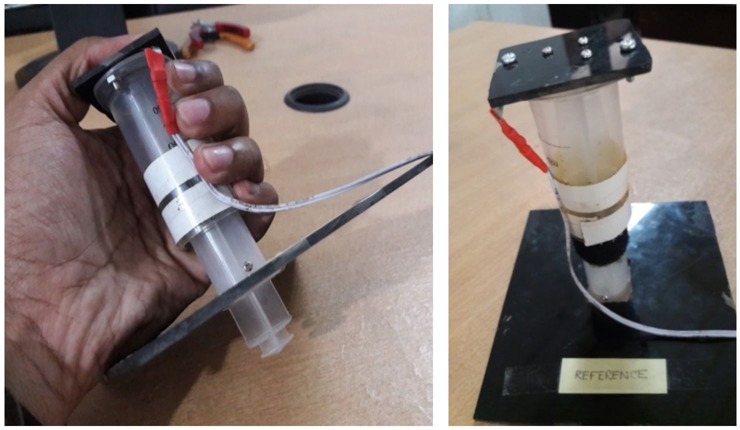

Fig.20: Two views of the preliminary working model of the Tele-Palpation device

Fig.21: The second prototype of the Tele-Palpation device (left), and its use on a human subject (right).

views of the preliminary working model of this Tele-Palpation device giving the basic functional system are shown in Figure 20. It gives the force information electrically but the plunger depth information is manual, through a scale at the side. The second prototype has both the information given as electrical voltages and Figure 21 shows the device (left), and its use on a human subject (right). That it gives a reasonably satisfactory performance is shown through the calibration graphs of Figure 22 and 23. The first one shows the output voltage of the pressure sensor as a function of the force applied on the top platform of the device. The second one shows the output voltage of the depth sensor as a function of the plunger depth. This has been achieved through the use of an infra-red LED and a photodetector fixed to the two parts of the plunger that moves relative to each other. Using these calibration curves it will now be possible to display the necessary information for the remote doctor on a computer monitor. This is world's first and is going to be a significant contribution to global Telemedicine.

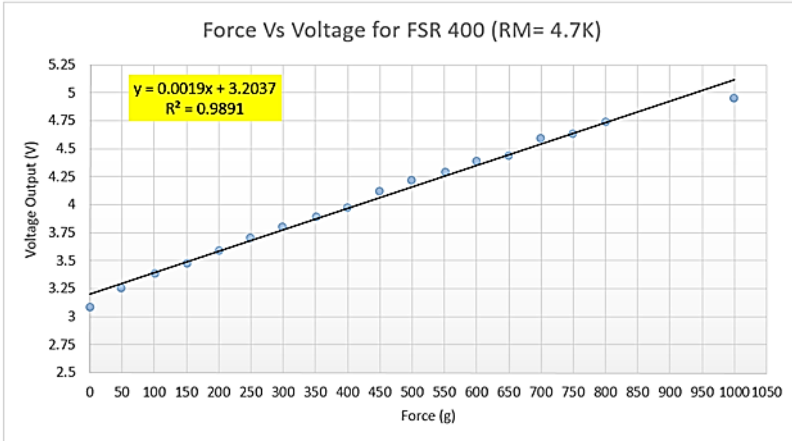

Figure 22: Output voltage of the pressure sensor as a function of the force applied on the top platform of the tele-palpation device.

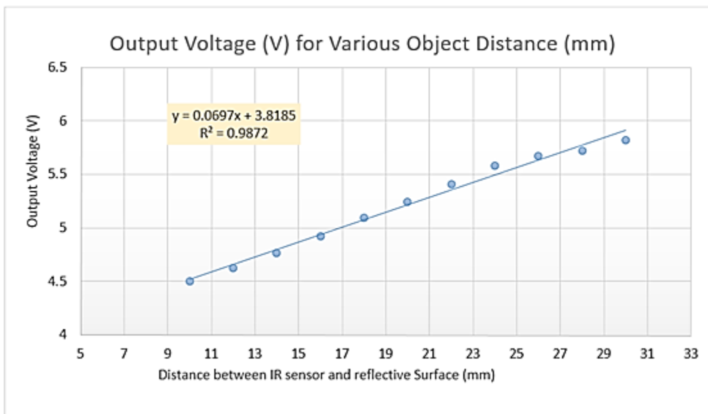

Fig.23: Output voltage of the depth sensor as a function of the plunger depth.

f. **Remote measurement of blood pressure:** In a normal peripheral artery blood flows smoothly in a laminar flow pattern, with no turbulence, so that no sound is usually heard on placing a stethoscope on such an artery. The classical non-invasive blood pressure measurement is performed using the principle of sound produced by turbulent flow of blood through an artery, the turbulence produced by external air pressure applied using a pressure cuff which restricts or obstructs blood flow through the artery. On raising the pressure of the cuff above the highest blood pressure in an artery (systolic pressure) the blood flow is stopped so that no sound is heard.

On gradually decreasing the cuff pressure a point is reached where the cuff pressure is just below the systolic pressure. Here blood flows during the very short time that the arterial blood pressure is higher than the cuff pressure, which is usually a turbulent flow, producing a pulsating sound (Korotkoff sound or K-sound) that can be heard placing a stethoscope on the artery. This gives the Systolic pressure. Again, on further reduction of cuff pressure a point is reached when the cuff pressure falls below the minimum blood pressure in the artery. At this point laminar flow is restored and no K-sound is produced. Thus the point where the pulsating sound just vanishes gives the lowest blood pressure, known as the diastolic pressure.

Currently another technique is being used, called the oscillometric method where listening to K-sound is not necessary, a pulsating pressure variation is noted above the peripheral artery during the changes in the cuff pressure as mentioned above from which a decision is made regarding the systolic and diastolic pressure. All automatic blood pressure equipment commercially available uses this principle, which does not need any training on the part of the operator who performs the measurement. Such a blood pressure measurement system could ideally integrate into a telemedicine system with ease. However, relationships between the onsets of the arterial pressure variations used in these devices to that of the K-sounds are not constant, rather these may vary under different physical conditions and from person to person. Hence doctors tend not to depend on these modern blood pressure devices, the old one based on K-sound is still gold to them.

Of course a remote operator (THO) can be trained on measuring blood pressure using the traditional K-sound based technique, this is what we are using at present. However, with a large expansion of telemedicine services, we may encounter operators who may not measure the blood pressure accurately, leading to wrong diagnosis. Therefore, in our system we planned to use an innovative method where the remotely placed doctor will measure the values her/himself, giving more satisfaction. This is again a new idea, nobody else in the world has tried this as far as we know.

In our method a pressure sensor will measure the cuff pressure while a stethoscopic sensor will pick up the sound from a specific point on the artery. We have already developed a digital stethoscope while a pressure sensor giving a digital data is commercially available. Both these digital data will be simultaneously sampled (through time multiplexing) in the main platform mentioned above and will be transmitted to the doctor via the website simultaneously where software will display the cuff pressure on the monitor while the doctor will listen to the stethoscopic sound through a headphone.

The doctor will instruct a THO to raise the cuff pressure of the blood pressure device attached to the patient's arm and to release the pressure gradually at a certain point. This instruction will be carried out through a video conference system. From the simultaneous pressure and sound information the doctor will be able to find the systolic and diastolic pressure points, giving her/him more confidence in the diagnosis. Since both the pressure and the sound data are transmitted simultaneously through the same digital channel through time multiplexing, there will be no relative variation in delay between these two sets of data. Any delay on the transmission path will apply equally to both the data and therefore, will not be a problem.

Connecting a pressure sensor to a blood pressure cuff through a T-joint, we have been able to get an equivalent electrical output. The electronic version of the stethoscope has already been developed. The circuitry for the main platform is also ready. Therefore, the next development to integrate both these devices to the ADC in the platform and attempt transmission of data for the measurement of blood pressure can be taken up soon.

g. **Software:** The system design has been finalised, as shown in Figure 24, the software development work has been accomplished to a reasonable level which is ready for implementation. Figure 25 shows a few sequences from the patient end on a mobile phone screen while Figure 26 shows a few sequences at the doctor's end. The last one is a prescription which the doctor generates using software aid. The interface is mostly in the local language, Bangla, however, some data and information are in English. The following link gives a video of the user interfaces that this software gives at both patient end and at the doctor's end.

https://youtube/EWBt6Wpr48Y

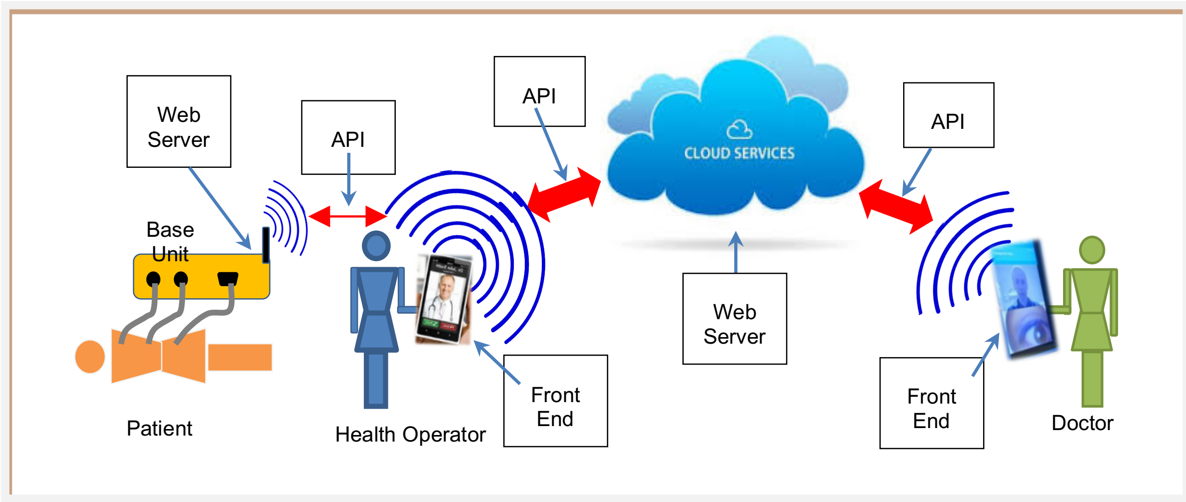

Fig.24: Software modules developed for the mobile phone based Telemedicine system shown in text boxes

Fig.25: A few sequences of user interface of the mobile phone based Telemedicine system at the patient end.

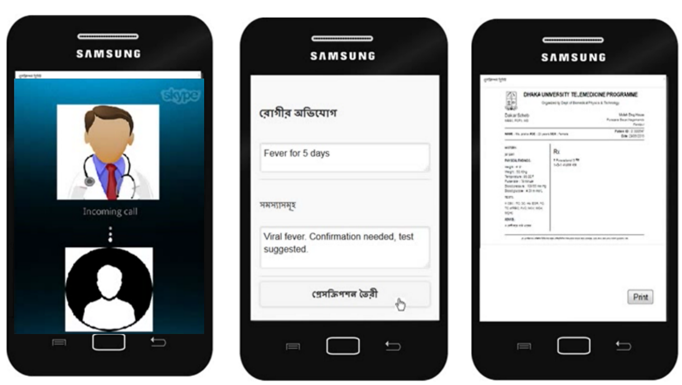

Fig.26: A few sequences of user interface of the mobile phone based Telemedicine system at the doctor's end including a prescription which is generated using software aid.

Indicators

Indicators	Baseline	Progress assessment	Course of action
How do you measure project progress, linked to your objectives and the information reported on the Implementation and Dissemination sections of this report?	*Refers to the initial situation when the projects haven't started yet, and the results and effects are not visible over the beneficiary population.*	*Refer to how the project has been advancing in achieving the indicator at the moment the report is presented. Please include dates.*	*We understand change is part of implementing a project. It is very important to document the decision making process behind changes that affect project implementation in relation with the proposal that was originally approved.*
Procurement of minor equipment	Our laboratory has some basic equipment and tools which were used in this project also. However, some specific items were required for this project which were not there. Besides for the developers, computers/ Laptops were needed.	We procured necessary minor equipment. However, some changes were brought, explained in the next column.	The list of minor equipment was changed somewhat from the proposed list – this is to divert funds to manpower sector. To do this without affecting the output, we used a lower cost version of an equipment and borrowed others from other groups of our laboratory.
Recruitment and training of research workers.	We had some researchers who earlier worked for the PC based telemedicine system whose expertise was available for consultation, but we needed dedicated research engineers and technicians for this project.	We recruited more workers than proposed later, as we needed to recruit more people to complete the task. The Project leader and the consultants trained the workers as and when needed.	We found out that the plan was too ambitious for a one year period. Besides, the stethoscope posed a greater challenge that we had envisaged. Furthermore, one worker left as he got an attractive career job elsewhere. Therefore, we engaged more people in the team later, some full time and some part time. Still there were a few who contributed to this project partially but were paid from our other projects.
Developed hardware of individual diagnostic items, modified to the portable configuration	In terms of hardware for this specific project, the baseline may be taken to be zero. Some of the items were done before for a PC and the knowledge and experience was useful, but those devices could not be used as they are, and had to be completely redesigned	The status is as follows. i. Stethoscope – two models prepared ii. ECG (12 lead, for real time and/or store & forward transmission) – PCB redesigned for the main platform of the portable unit. At final stage. iii. Respiration monitor (for real time/semi real time transmission). Developed PCB working on new platform. A special electrode probe has been designed and developed for both adults and children. iv. Thermometer *working on new platform.* v. Blood SpO2: temporarily kept on hold, will be done later. vi. Tele Palpation: Prototype working, a World's first. *vii.* Remote Blood Pressure monitoring: temporarily kept on hold, will be done later.	The main purpose was to develop the basic technology of the system. We concentrated on the challenging aspects which have already been tackled. There are a few simpler problems which remains to be done but these can be tackled later successfully.
Developed single portable main platform with combined hardware.	Zero (we did not have anything like this compact solution earlier)	Main Platform with multiple (8) input slots, isolated power and WiFi link to an Android tablet PC or mobile phone: designed and prototype made.	The main platform is quite a complex piece of hardware and needed very concentrated and skilled handling. We took it up towards end as that gave us a clear view of what configuration would be demanded by the rest of the hardware. Usually such designs succeed after several failed ones, but thanks to our skilled young designers, it was successful in the first attempt. However, when we go for a commercial prototype, some minor changes may be brought about from the experience of operating this unit.
Developed software to acquire and transfer data for the above individual diagnostic items and for telemedicine (patient registration, patient information entry, doctor's prescription generation, etc.)	*Zero. The software developed for a PC gave us knowledge and experience that was useful, but had to be developed completely afresh for the mobile phone based system.*	Software for web hosting, mobile phone interface at health operator's and at doctor's end developed.	The software was developed by mainly two persons one of whom was not paid from this project. They have tackled most of the problems during the project period. However, when we actually implement the system in the field, further minor modifications may be needed. Also we may develop it in other languages if there is a demand.

Project implementation

Project activities	Input	Outputs	Timeline	Status
Actions taken, work performed.	*Financial, human and material resources*	*Result and/or deliverable produced as a direct result of the project activity. Outputs are under direct control of the project team.*	*Dates where the listed activity was developed.*	*Indicate when the activity started, on-going or completed.*
Procurement of minor equipment.	Oscilloscope, Laptop, Tablet computers procured. Other items borrowed from host department.	Setting up of laboratory facility including minor equipment and tools.	15/05/2015 – 15/12/2015	Completed
Recruitment and training of research workers.	Initially 2 full time and 2 part time research workers recruited. Later, 2 more part time workers and 2 part time consultants recruited to expedite the work. All of them trained on-job.	Trained technical human resource for achieving the objective	15/05/2015 – 15/12/2015	Completed
Development of mobile phone interfaces for the following: i. Stethoscope (with low frequency sound capability) j. Respiration monitor (electrical impedance based) k. Diagnostic ECG l. SpO2 monitoring m. Ultrasound Foetal Doppler n. Tele-palpation o. Remote measurement of blood pressure p. main platform with microcontroller, isolated power supply, WiFi and USB interfaces, sockets for diagnostic devices. .	Above mentioned hardware and trained human resource in addition to raw materials and components, procured as and when needed.	A compact portable box with the equipment mentioned in column 1, all interfaced to a mobile smartphone	15/07/2015– 30/06/2016	Basic Technology development – completed [SpO2 and Remote measurement of blood pressure kept on hold as the other items were on priority and time was not enough to develop these two items. However, these two will not pose much challenge and will be developed later]
Putting together all the above in a compact portable box.	Readymade aluminium framed box	Packing all the developed components in the box in an user friendly way	Will be done later, for commercial prototype	Will be done later as a part of the process for commercial prototype.
Development of user friendly software for telemedicine incorporating the above facilities	Laptop, Mobile phone and software development tools procured.	User friendly software for telemedicine using mobile smartphones	15/10/2015– 30/06/2016	Basic Technology Completed

Communication and dissemination

Matters related to development of technology for a mobile phone based telemedicine system under the ISIF-Asia grant 2015 were reported by the Project Leader at the following workshops and conferences:

- K S Rabbani, A brief report sent to JFDI Accelerator, 21 September, 2015: A mobile phone based Telemedicine system with integrated diagnostic equipment.
- K S Rabbani, Telemedicine for Rural Areas (PC and Smartphone based), Keynote speech, bdNOG4, November 10, 2015.
- K S Rabbani, TEIN Application Workshops 2015, Bangladesh Research and Education Network (BDREN), Workshop on Telemedicine: Issues and Challenges, 20 - 21 October, 2015, (BSMMU), Dhaka-1000, Bangladesh.
- K S Rabbani, Potential of indigenously developed Telemedicine using Internet - Local Solutions with Global Potential, Keynote lecture, bdNOG5, 11 April 2016.

Project Management and Sustainability

Although money was available around mid-May 2015, recruitment of Engineers and training them up took a while and actual work started in July 2015. Again, because of multiple things to be developed in such a short time, we had to recruit extra manpower, some on a part time basis. As can be seen in this report, the basic technology of the prototype has been developed. The amount of development done in this short period of one year was due to the dedication and sincerity of the whole team. Now this will have to go through further modifications and improvements so that a commercial model may be placed on the market.

We have already established a strong research culture in our department prior to this grant, engaging about 15 Physicists, engineers, doctors and microbiologists working in the team. The ISIF grant has enabled us to expand the research base and human resource to complement the previous activities. We have both hardware and software engineers in our team which have been strengthened through recruitment of two full time and two part time engineers. Previously, we did not have strong android programming skills in our group, this recruitment will help fulfil that weakness. Besides, two senior experts in our team have also been engaged as consultants, giving occasional guidance and help. Recently, another software engineer has been recruited who will give part time to this project beyond his other development projects of our larger team.

The project leader trains researchers allowing each individual to gain his or her own competency first through independent efforts towards fixed specified targets, occasionally providing guidance as required. The development process appears to be slow in the beginning, but eventually the members become mature and independent, the pace picks up, and a great deal of work is accomplished in a short period. This is a lesson the project leader has learnt through his lifelong experience. A similar scenario is expected with the present project as well; an apparent initial delay was observed, but eventually this was covered up. The amount of development done in this period of one year (please see the project narrative above and the annexure) is quite striking and shows the success of the leadership philosophy mentioned above.

The development of a live stethoscope posed quite a bit of challenge as mentioned earlier and took a while to sort out. Since the number of items to be developed is a bit too many for the period concerned, we made some small changes in the plan. We found out that we needed more research workers than that stipulated originally, so we changed the plans of procurement of some minor equipment to pay for the extra human resource. We arranged to borrow some of these equipment from other laboratories in the department, when needed.

Since the present project is very time bound and the personnel have gathered necessary expertise in the initial period, we started to have regular weekly progress meetings after the initial few months. This has also contributed in the improvement of the organisational practice in our laboratory.

As mentioned earlier, we are already engaged in field trial of our PC based Telemedicine system. 9 rural centres are running and another 4 are preparing to provide the service. 8 doctors, including several lady doctors and specialists in Gynaecology, cardiology and dermatology are giving consultation. The centres are rural enterprises that have been established by individual entrepreneurs with our support. We are trying to develop a self-sustaining model where revenue earned from the patients will be adequate to fund the whole activity. However, it will take another year or so to see such sustainability in a few centres at least. Our programme has been permitted by the Director General of Health of the Government of Bangladesh and the University of Dhaka in its Syndicate decision has named it as ‘Dhaka University Telemedicine Programme’. ‘Access to Information’, a programme of the Bangladesh Government supported by UNDP and USAID gave us a grant for this field trial and we are now trying to get funds for extension of the programme. We are hopeful of receiving support in different forms from other organisations as well.

The above infrastructure that we have already created will be helpful when we are ready with the mobile phone version, being developed under the present project. This earlier activity has already prepared the scenario for a field trial of the new technology. The same rural enterprises can hire health workers who will attend patients at homes using the developed system. Besides, we hope to use the self-sustaining model here too, although some support may be necessary in the initial phase. The rural health workers who will be involved in the dissemination of the mobile phone version will be mostly women and therefore, this project will eventually contribute to a greater role by the females in the society. Also, women, children, the old and the infirm will be benefitted more when the output of the project is put into practice since these categories of the rural population are less taken care of normally.

Project Outcomes and Impact

The output of the present project is the development of technology for telemedicine with integrated diagnostic equipment, based on mobile phones while the outcome is the provision of quality telemedicine to rural population at individual homes, through roaming health workers. The prospective benefit to the population is huge. In countries like Bangladesh where almost 70% of the population live in the rural areas, where consultation of a qualified doctor will remain a far cry for decades to come, telemedicine offers a realistic intermediate solution. While many on-going efforts on telemedicine are based mostly on audio-visual links only, the outcome of the present project is going to improve upon these efforts significantly, integrating a number of diagnostic devices, most of which are indigenously developed and manufactured.

The benefits of indigenous development and manufacture of medical devices are huge, particularly when one deals with telemedicine in which tens or hundreds of thousands of health workers equipped with these devices are involved in a low resource country. One cannot sustain a telemedicine system in a low resource country using equipment and software imported from rich countries. Firstly, the cost is usually very high as the cost of the imported equipment has the high wages of the rich countries behind their development and manufacture. One can easily guess the total expenditure for all the thousands of centres, making it practically impossible for a low resource country to procure in the first place. Secondly, most imported medical equipment cannot endure the extremes of weather and power line fluctuations encountered typically in countries like Bangladesh and fail after a brief period of use; sometimes even before use. Thirdly, maintenance and repair is difficult and expensive. Sometimes it is more practical to throw away a non-functioning device and buy a new one rather than getting it repaired. This is because spares are not readily available and there may not be any local expertise for the job. Particularly, in modern days, when microcontroller based devices are in abundance, technical secrecy of the manufacturers make it virtually impossible to repair, even if necessary expertise is available.

Therefore, when one has a system with tens of thousands of medical devices spread throughout the country, if many of these devices remain out of service for more than a few days, the whole service would suffer, and people may lose confidence in the telemedicine system, making the effort unsuccessful at the end. Our experience with imported hospital equipment matches very well with this observation. Finally, human interface of imported devices, their instruction manuals, software, etc., are not necessarily geared to local culture, customs and understanding, making the acceptability of the telemedicine system difficult.

On the other hand, if scientists and engineers of the country in question develops and manufactures the devices locally, most of the above difficulties will be removed or lessened and it will be much better option for introducing a mass service like telemedicine. Therefore, the aim of our group at Dhaka University since the early eighties was developing indigenous capability in medical device development which has reached quite a reasonable status now. We hope to be able to develop the Telemedicine system successfully with this acquired capability.

Subsequently, we hope to organise a training programme through which we can teach and train scientists and engineers from other low resource countries, so that they are able to develop and manufacture essential medical devices including telemedicine systems indigenously. As mentioned before, we have a philosophy of not patenting our innovations, rather we will disseminate the technology freely to all countries of the world in the above way so that people in each country can get sustained benefits of modern healthcare technology in an affordable manner.

We hope the impact this effort will make on global health eventually, will be great.

Overall Assessment

Healthcare is a basic necessity and the outcome of the project is aimed at the healthcare of a majority of the population in low resource countries who live in rural areas where qualified doctors are not usually available. Therefore, the project, which offers a solution to the above problem, is very important having a global perspective.

Through this project we have developed the basic technology for a mobile phone based telemedicine system with integrated diagnostic devices. As soon as these are ready to be deployed, hopefully in less than a year, we will try to incorporate this technology to extend the PC based telemedicine programme that we have in Bangladesh at present. Through this trial we plan to refine the technologies over a further period of about one year. After this we will explore the possibility of involving and training scientists and engineers of other low resource countries so that they can use our system, modifying it according to their local needs and environment, and deliver the benefits of this research to their own population. Side by side, our research efforts will continue for incorporating more diagnostic devices to this system and to improve the software.

The project has a potential contribution to development to all the low resource countries of the world. Even rich countries may benefit from this as they have specialised requirements for telemedicine as well.

Most of our previous research programmes are not very time bound, as we allow the workers to acquire the necessary expertise and create new ideas. However, this project was rather time bound, which we could take up because of our past preparation. Without this preparation we could not have taken up this work for achieving something visible within a year or so.

The personnel involved in this project actually went beyond the ones actually employed under this project. Several other researchers have contributed in some way or other to this project. This has expanded the interaction among our researchers which will have a long term benefit.

The motivation of our laboratory has been the innovation of appropriate or relevant science and technology to enhance the quality of life of the deprived segment of the humanity, a philosophy evolved and nurtured over a few decades of committed work by the project leader. This attracted many young researchers to this laboratory. The present project allowed us to successfully innovate and develop technology to a level that the young developers themselves did not comprehend earlier. This was possible due to the knowledge and experience of several decades of the project leader in modern technologies like electronics, computer interfacing, and biomedical engineering and the talents and preparations of the young members with recently developed technologies. They could interact easily and this cross-coupling of ideas and capabilities resulted in practically usable products within a short time. Besides, that with the knowledge of science one can indeed design things simply and at low cost surprises many. For example, the Tele-palpation unit was a completely new idea. The

Project leader could visualise it due to his long experience and expertise in Biomedical Physics and Engineering. Again, the use of a simple plastic cup for a stethoscope was a surprise for many, which was a natural consequence of the long association with science and technology. The electrical impedance technique to monitor localised lung function also depended on a simple innovation of the project leader, known as 'Focused Impedance Method (FIM)' which has been acknowledged by the international scientific community working in this area.

Apart from the present project, the project leader has been working together with his young student team in several other areas and an important innovation was a very low cost solar water Pasteuriser costing about USD 5 which the rural people can make themselves using commonly available material. He also has a major innovation in neurological measurements, a new parameter that he introduced, which can detect low back pain or neck pain because of neurological causes at an early stage, even before a person feels the pain. Again, he made the instrument needed at low cost to measure this new neurological parameter, making the detection and diagnosis affordable, in the low resource countries as well as in the developed countries. He also developed a device to map dynamic foot pressure, particularly needed for diabetic people to prevent foot ulcers and possible amputation of the legs. Some of these devices are already working in neighbouring countries. Some of these developments may be integrated to the Telemedicine system in the near future.

Coming to this particular project, the amount of development that took place in the span of only one year is remarkable. The young group has seen how the guidance of an experienced senior can give useful and successful outcomes through their inexperienced but talented minds and hands in a short time span. This is not very common in countries like Bangladesh, particularly in science and technology as most of our technically talented persons have chosen the West for their activities - an expensive 'brain drain' for these countries. The talented young people, with immense interest and energy and enthusiasm, mostly have to work out themselves through the challenges without any guidance, which brings failure and frustrations in many cases. Finally either they end up in the developed West if they get the opportunity, or have to remain satisfied with day to day mundane activities in organisations utilising foreign technology based equipment where there is no scope for creativity.

Working under the present Project Leader, the young people have seen how small developments in science & technology can bring big changes in the lives of the common people in low resource countries – a fact that is often masked by glamorous research on high technology that are mostly promoted by traditional institutions in low resource countries.

The project leader took care of all the aspects of innovation – right from basic R&D to their implementation – which involved manufacture and/or dissemination activities. Although there are separate organisations in the West who take up such segments of technical innovations, but this is totally absent in our countries. Many researchers in the local universities eventually get frustrated as they have in mind the picture of the Western countries and keep waiting for someone to take up their innovations, which obviously never happens. The project leader could understand this aspect quite early in his life and had turned himself an entrepreneur to commercialise his own technologies even when he was in his mid-twenties. Therefore, in countries like Bangladesh where many talented scientists and technologists end up in frustration at the end of their career, blaming the administration or the other, the present project leader had never suffered from such frustration as he understood the real picture and took necessary steps himself to fill in the gaps. Thus, even though he has formally retired from the University's active service only a few days back (30 June 2016), his sphere of activities have in fact increased and the University has already appointed him an Honorary Professor. The project leader also feels that his decision to come back to his country after obtaining a PhD 38 years back refusing lucrative offers in the West was right. The motivation to do something to enhance the quality of life of the deprived humanity using science & technology that was behind his decision has in fact worked. It is not only the technologies that has been innovated through his leadership and which are being used by the common people, the view of a host of talented youths flocking around him putting the best of each one without having any strict rules or regulations imposed on them makes him feel happy and feels him with gratitude to the Almighty that his life has at least been useful to some extent.

Recommendations and Use of Findings

The main users of the outputs of the present project would be Telemedicine service providers in the rural areas of Bangladesh and in countries having similar social and economic conditions. Such pioneering activities will bring out other factors – technical, social and economic – that will need to be addressed. Eventually the experience will have to be used to rectify and improve upon the technology as well as the mode of implementation. This will create a robust telemedicine system including technology and implementation modality which may eventually be used by national policy makers for a large scale implementation of the technology for delivering the benefits to all the rural people.

As recommendations for other similar groups, the following points are worth mentioning.

R&D work with a definitive target teaches and prepares the team members for higher and higher challenges. Particularly in technology, there is no alternative to doing things in practice.

While having the group meetings in the early period we used to discuss things through writing on paper, scribbling or drawing rough diagrams. This engaged only those who were directly involved, the rest appeared to be disengaged, remaining outside the discussion. Then we introduced a camera on a stand projecting the writings onto a screen. This improved the environment; everyone could get involved and could have a feeling of being together. Besides, this opened up the opportunity for contributing to innovations of a particular segment by people working in other segments – which usually comes out to be very important for the final design of the technology. A tablet computer with handwriting stylus could be an option, but most styluses have a broad tip and are not suitable for fast and coordinated scribbling required in such discussions.

When there was some sluggishness in a segment of the work, either due to technical challenge or due to incapability of those responsible for that segment, or due to a lack of enthusiasm, some of the other group members had a tendency of blaming those responsible for that segment. This is typically observed in most team work environment. The group leader through his lifelong experience knew that this was wrong and he tried to change this attitude through preaching that one should try to find the reason behind the delay or apparent failure and find out ways of rectification rather than blaming and isolating someone. If the person has a lacking, others should try to help him or her first through directly participating in the work involved. Most weaknesses can be rectified through this approach. In case the person is found to be incapable, the leader should find a segment of work that suits the capability of the person. There is a saying, ‘a good leader creates leaders, not followers’. The approach should be creation of leaders out of each member in the group. Only then the group performance can improve and a desired target can be achieved in the least possible time. This is an important lesson for any group.

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