POA_S@UDE

A New Collaborative Tele-ultrasonography System over PLC

Alécio Pedro Delazari Binotto[1,2], Valter Roesler[1], Cirano Iochpe[1,3], André Campos da Cunha[4]
Ronaldo Husemann[1] and Carlos Eduardo Pereira[1,2]

[1]*Informatics Institute, UFRGS - Federal University of Rio Grande do Sul, Av. Bento Gonçalves 9500, Porto Alegre, Brazil*
[2]*CETA - Center of Excellence in Advanced Technologies SENAI, Av. Assis Brasil 8450, Porto Alegre, Brazil*
[3]*PROCEMPA - Information Technology Company of Porto Alegre, Av.Ipiranga 1200, Porto Alegre, Brazil*
[4]*Maternal-Infant Hospital Presidente Vargas, Porto Alegre, Brazil*

Keywords: Telemedicine, Ultrasonography Images/Videos, Real-time Collaboration, Multimedia.

Abstract: Access to medical care is sometimes difficult to be reached by citizens living in distant and underserved areas. The problem increases on high complexity medical cases that are not preventively identified. The recent advance of broadband communication, like Power Line (PLC), combined with state-of-the-art multimedia compression methods allowed reaching isolated areas that lacks of intra/internet connections. This paper presents the results of the POA_S@UDE Project, a research that aimed the improvement of patient quality of life in distant urban communities from high-complexity hospitals, focusing on obstetric ultrasonography (U/S) examinations during prenatal period. Statistics show an obstetric examination miss rate higher 60% at the Restinga peripheral district (100,000 inhabitants) in Brazil. The main reason is the time and financial difficulties to go to central hospitals to perform regular examinations; added with the time gap of 4 months between an exam request and its realization by the referral hospital. Based on that, we introduce a collaborative tele-U/S system over a PLC hybrid network based on multimedia data. The specialist doctor assists, guides, and interacts in real-time with the remote doctor who operates the U/S equipment. At Restinga, during a pilot of 3 months, the examination waiting time was decreased to 1 month and the miss rate of prenatal examinations to 30%.

1 INTRODUCTION

Telemedicine represents a multidisciplinary research area. It integrates not only efforts of various fields from Computer Science, but also different disciplines from medicine and other health areas. In addition, it can involve public health policies, government strategies and public organizations. This way, telemedicine is currently growing as a complex research topic for the improvement of health services, of population quality of life, and also for remote medical training, including resident physicians. Based on this advance, the qualified health care of excellence medical centres is extended to remote and underserved areas with the indispensible government support.

Therefore, most telemedicine applications are massively video/image-based (data from U/S, CT, X-ray, resonance, etc.), being used not just for teleconsultation, but also for a simple second or third opinion, repository research or remote training through the Internet. Those are applications that aim, chiefly, to provide technical support on decision-making of non-specialist doctors, who often work in places distant from medical excellence centers.

However, this strategy depends completely on Internet bandwidth and its reliability and data security. Thus, due to the precarious scenario of poor regions, the mentioned telemedicine applications present features that originally do not require synchronous and real-time communication nor need to deal with large data transferences, like video, images, textual, and voice.

Regarding U/S examinations (the focus of our research), it must be performed by doctors specialized at the medical discipline related to the exam (e.g., obstetrics, fetal medicine) and experienced with the equipment. Particularly in Brazil, other professionals besides doctors cannot

Delazari Binotto A., Roesler V., Iochpe C., da Cunha A., Husemann R. and Pereira C. (2009).
POA_S@UDE - A New Collaborative Tele-ultrasonography System over PLC.
In *Proceedings of the International Conference on Health Informatics*, pages 222-229
DOI: 10.5220/0001541902220229

operate the equipment. When the local physician lacks the knowledge or experience at the medical discipline to perform the exams in order to acquire meaningful videos for interpretation, the local doctor must take the responsibility for the final exam diagnosis, communicating with the specialist physician who guides all the examination and together can generate the final diagnosis. In this case, it is suitable that both doctors have a synchronously data communication in real-time, mainly at the data acquiring phase, i.e., videos generation.

When synchronous communication of images with good quality and real-time is required, many factors related to network and multimedia areas must be taken into consideration, such as bandwidth, audio and video codification, processing capability of the involved equipments, and the end-to-end communication delay. Usually, these factors determine the final video quality.

In tele-U/S, real-time applications present specific features that demand more resources from the computer system. In this paper, real-time means both sides communicating and not feeling uncomfortable with the delay. According to (Bartoli, 2007), this time should be less than 400ms in IP videoconferences to meet ITU (International Telecommunication Union) standards. In order to accomplish this, our research is based on MPEG-4 video codification, offering real-time collaborative point-to-point tools.

Regarding communication, our case study is deployed over the power lines, designated PLC (Power Line Communication) in Europe and BPL (Broadband Power Line) in the United States. The data communication through electric power nets is already an alternative that competes and/or complements the wireless communication systems, satellite and wired applications, like cable TVs (Opera, 2007). We choose that type of communication, since it is a distinct parallel project developed by part of the authors in the same region of the presented case study.

Based on that, this paper presents the results of an innovative telemedicine pilot service over PLC, named POA_S@UDE, performed at the city of Porto Alegre (Rio Grande do Sul State, Brazil) and its poor and remote district called Restinga. The paper is organized as follows. It starts in Section 2 with a brief motivation and description of the medical scenario, followed with previous and parallel work on projects in the telemedicine and PLC areas in Section 3. The proposed platform is detailed on Section 4, emphasizing U/S obstetric examinations over a hybrid PLC network. Finally, on Section 5, we present medical, technical, and social results achieved during the pilot and discussions about its benefits and future directions.

2 MOTIVATION

At Porto Alegre (1.5 million inhabitants), the Maternal-Infantile Hospital Presidente Vargas (HPV) is a medical referral center focusing pregnancy. The public hospital assists a vast part of the population who lacks of specialized maternal infrastructure. Most of its patients come from remote districts just for the accomplishment of routinely U/S examinations and for accompaniment of pregnancy evaluation.

Restinga is the poorest and most remote district of Porto Alegre, having more than 100.000 inhabitants with a population density of 23 inhabitants/ha, occupying more than 20.000 homes. The growth tax between 1991 and 2004 was 5.6% per year and the average monthly income of the answerable for the domiciles is 3.03 minimum wages. The district counts just with a small health center and lacks of specialist physicians and basic medical devices, which sums up an average of 300 patient transfers to HPV per month for basic ultrasound examinations, being more than the half in the field of obstetric/gynaecologic. In this manner, it overflows the HPV capacity with patients that, in the majority of the cases, could be assisted in their own district by available General Practitioners, the residents, whom could be guided by an expert doctor using a basic structure with U/S and internet connection. In fact, most of the cities have a basic structure of general doctors who, very often, cannot give a final and correct diagnosis without a second medical opinion or assistance/discussion.

According to the WHO - World Health Organisation (WHO, 2008), women need to visit a hospital at least 4 times during the pregnancy for periodically accompaniment. However, at Restinga there are cases where the patient visits the hospital for the first time just to give birth. To better illustrate the precarious scenario from that region, there is an obstetric examination miss rate higher that 30% in U/S exams for pregnant woman at Porto Alegre and more than 60% at Restinga. In addition, Restinga presents a time gap of more than 4 months between an exam request, by the periphery health center generalist physician, and its realization by the specialist doctor of the HPV.

3 PREVIOUS EXPERIENCES

In the recent past and at present, some technological projects aiming social inclusion were developed at the Rio Grande do Sul State. Two of them, T@lemed and PLCRestinga, are the infrastructure basis for the presented system. The first deployed an image-based telemedicine system over the State, while the second integrated Restinga's public buildings using PLC, since there was no fast internet connection until the year of 2006. The next sub-sections go in detail over these projects, as well as give an overview about other related work.

3.1 Related Work

The Brazilian Government, through the RUTE (University Telemedicine Network) initiative - (Rute, 2008), (Simões, 2006) - has been investing at the development and online availability of knowledge databases related to health. The goal is to subsidize the decision-making of health professionals who act far from the reference medical centers. It is a try to improve decision quality and reduce the "ambulance-therapy" phenomenon.

Another situation was presented by (Sibert, 2008), which performed an experiment of U/S laryngoscopy images and video transmission in rural emergency situations. The images were transmitted from the ambulance through mobile phones 3G connection, but in low quality. Results showed good system acceptance by the doctors, but with remarks regarding image quality.

In the work of (Yee, 2005), an experience similar to the one presented here, two hospitals in Australia made transmissions of the ultrasonography device screen aiming a third medical opinion. They tested over several network rates and came to a conclusion about the best cost-benefit rate for a good video quality. It was a bandwidth around 1Mbps.

The work of (Reddy et al., 2000) proposed a solution for fetal tele-U/S in remote canadian communities, where 49 patients were observed in remote obstetric ultrasound examinations. The practical environment comprised two personal computers linked via 19.2 kbps modem over an analog telephone line.

In addition, (Chan et al., 2000) proposed a real-time transmission of fetal ultrasound images over long distances via ISDN lines. A link of up to 2 Mb/s was established. The proposed system incorporated built-in interactive two-way microphones, allowing direct communication between both sites. Examination video has been captured by dedicated video boards and transmitted in rates of 30 frames per second. Over a 3-month pilot period, 24 tele-U/S examinations were carried out. Overall, the consultations resulted in modifications compared to clinical diagnosis in 45.8% of the cases and modifications to the management plan in 33.3% of the cases.

3.2 T@lemed

Following the telemedicine concepts, the T@lemed Project (T@lemed, 2007) was based on a teleconsultation platform, named TeleConsult, which was developed by MedCom GmbH and the Fraunhofer IGD and allows store-and-forward DICOM image-based tele-diagnosis in on-line mode or either off-line.

The TeleConsult software platform is based on TeleInViVo (Kontaxakis et al., 2000), which is a telemedicine workstation used in isolated areas such as islands, rural, and crisis situation areas. The system integrates in one custom-made device a portable PC with telecommunication capabilities and a light and portable 3D ultrasound station, combining low price, low weight, mobility and a wide range of non-radiating examinations. The integrated workstation used advanced techniques able to collect 3D U/S data, which were presented on (Sakas, 1993) and (Sakas et al., 2000).

For T@lemed and for this research, the reason to work with ultrasound data is based on its support to a very large range of applications (Ferrer-Roca et al., 2001), varying from gynaecology and abdominal scans to cardiological examinations. Currently, it is the only economically and practically affordable imaging modality.

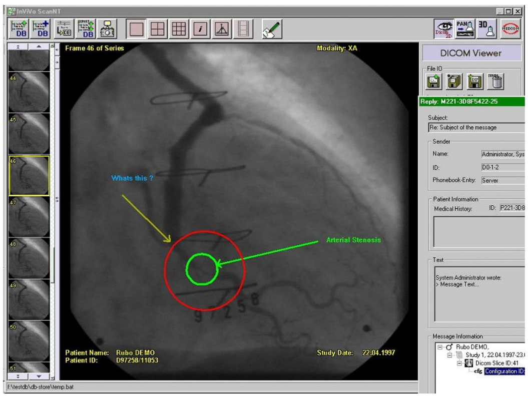

Figure 1: TeleConsult collaborative annotations.

As an example of its functionalities, after the data transferring, interaction can be made in real-time. Digital annotations in the medical images can be made by the generalist and sent to the specialist physician, aiming to delineate some region of interest to be argued. The data sending can be carried through an off-line connection, where messages (images + annotations + first opinion + other crucial region of interest) are sent in determined moment (at night, for example) and later on, at another moment, the specialist performs the diagnosis or opinion; or through an on-line connection. In this last way, depending on the bandwidth, the data are transmitted in few seconds and collaborative discussion (annotations + chat + voice + measurements + interaction), is carried in real-time. Figure 1 depicts an annotation interaction.

In the scope of T@lemed, doctors from four remote cities of the Rio Grande do Sul State were connected over wired internet (512Kbps) with a referral hospital located at Porto Alegre.

3.3.1 PLC Restinga

The PLC Restinga Project, PLC network at Restinga, arises to supply an economical gap promoted by wire telecommunication companies to attend deprived communities. Concerning the work of (Borges, 2005), the digital inclusion goal in Brazil is to look for the population (or at least its great majority), to be able to receive access to tools, services, and necessary technological abilities in the new economy. The PLC technology implementation cost and installation, using the medium tension net for data transmission, could be cheaper than the costs of available technologies.

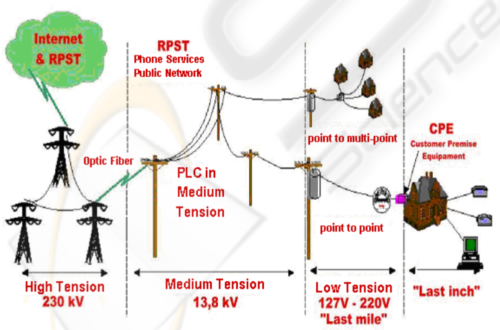

Figure 2: The PLC network at a whole.

With further technological details, we can basically classify the segments of communication networks via PLC in 4 areas, but the following 3 were used in our work (see Figure 2):

- **Medium Tension:** interval between the electric power company substation and the transformer of low tension that serves the final consumers;
- **Last Mile:** interval of electric net in between the transformer of low tension and the consumer's residence;
- **Last Inch:** interval of electric low tension net located in the consumer's dependences.

Taking advantage of the fiber optic network from the Information and Communication Technology Company of Porto Alegre (Procempa), which is interlinked to the optic ring from the State Company of Electric Energy, a PLC network was deployed, beginning from the substation, located in one of the extremities of the Restinga neighborhood (point 0 in Figure 3). In addition, four different points are connected, chosen from its geographical position and lack of digital services: (1) public primary school; (2) district administrative center; (3) professional primary school; (4) the previous cited Resting health center.

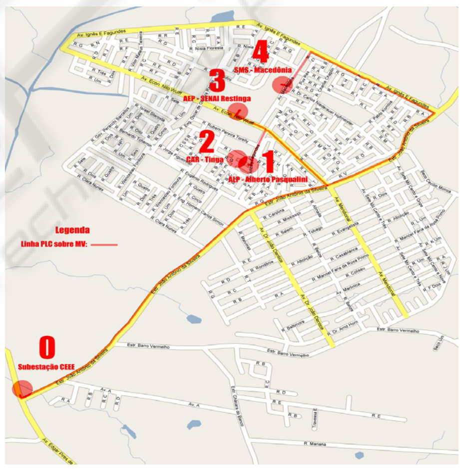

Figure 3: PLC medium tension map at Restinga.

The pilot reaches a linear extension of approximately 3.5 kilometers of PLC, transmitting data in high-speed (45Mbps, since we use the first generation of equipments) on the electric network of energized medium tension (13.8 kV). The project foresees several services, taking maximum advantage of the communication speed. Thus, its importance for telemedicine applications that needs normally high bandwidth when dealing with multimodal (large image/video data, voice, etc.) high quality data.

The network implementation was only possible due to the optic fiber channel located at the substation (point 0), i.e., it is a hybrid network topology and the PLC phase accomplishes the “red” lines of the figure. At a glance, starting from this point, the sign from the optic fiber is injected in the medium tension net throughout capacitive couplers and goes direct trough the electrical line, with acceptable losses, in distances of up to 1200 meters, where regenerators modems are installed aiming the system sign losses reconstitution. Repeating modems are also installed in these points to overlap the maneuver keys and the derivations in the medium tension net. In the extremities, special modems are used and receive the PLC signal from the medium tension and re-inject this signal in the electric net of low tension (127V/220V). The signal that arrives in the assisted points through the low tension is extracted from the power plug using a modem for low tension.

4 THE POA_S@UDE PLATFORM

Based on physician needs, the proposed system should compromise with the following concerns:

- **Good Ultrasound Video Quality:** show details in the ultrasonographies. This demand is subjective and the adequate quality is determined by the doctor when he can distinguish the meaningful regions of the fetus needed to perform the correct diagnosis and taking responsibility for it;
- **Perceptible Movements:** should show matters as mainly the **fetus heartbeats and the respiratory system**. This demand is also subjective and also determined by the doctor;
- **Audio Communication:** between the specialist doctor and the support resident physician;
- **Remote Pointer:** the specialist doctor can show details to the patient and the resident physician (who is with the patient). It uses its mouse inside the ultrasound area and the mouse movements are send to the remote place, showing specific areas which the doctor wants more attention;
- **Hand Probe Position:** video showing the hand of the remote resident physician, which shows the transducer position on the patient's abdomen.

Figure 4 shows a schematic of the developed solution. At both ends, there is audio coding and transmission. In the remote module, the system receives the video signal from the U/S and the hand position of the attendant, composing both videos on the same screen. The attendant hand is in PIP (Picture in Picture) form, generating a small resolution video. This signal is coded in MPEG-4 and transmitted live, being received by the doctor, who analyses it and communicates by audio and through the remote pointer, giving instructions.

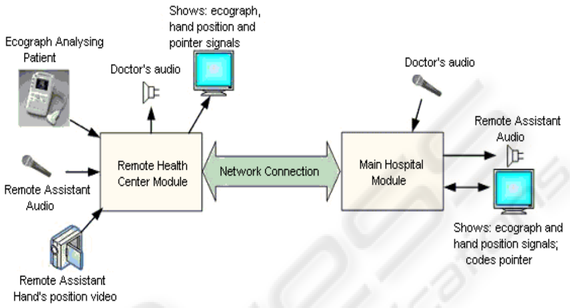

Figure 4: System Overview.

The TeleConsult was used to capture the U/S signal that is sent through the PLC hybrid network from the remote health center to the referral hospital. In our case, there is a non-specialist physician (a 4th year resident) who performs the exam. At the main hospital (HPV), the specialist doctor is responsible to assist, guide, and interact with the non-specialist in order to perform the final diagnosis.

The system internal structure, placed at the health center, is shown on Figure 5. A short description of each module is presented bellow:

- **Capture:** responsible for receiving the audio and video signals generated by external equipment, such as camera and microphone, independent from the communication interface (DV, acquisition card or USB). In the specific case of tele-ultrasonography system, the capture module received four simultaneous captures: a) the U/S video signal; b) the video signal showing the attendant's hand position; c) the attendant audio; d) the video monitor image;
- **Audio and Video Coding:** responsible for compressing the audio and video streams, captured for later transmission. The generic interface allows working with different coding algorithms. The available video coding algorithms are MPEG-2, MPEG-4 e H.264 protocols, and the audio coders are G.711 and AAC (Advanced Audio Coding) protocols. In this case, the coding was

compressing the audio and image from the video monitor;

- **Network:** implements the point-to-point communication between the local and the remote locations.
- **Audio and Pointer Decoder:** decodes the audio that comes from the main hospital, as well as the pointer signal controlled by the doctor;
- **View:** shows at the video monitor: a) small-sized image of the attendant hand position; b) large-sized ultrasound image; c) remote pointer image, controlled by the doctor. Besides that, it decodes the doctor's audio and presents it on the speakers.

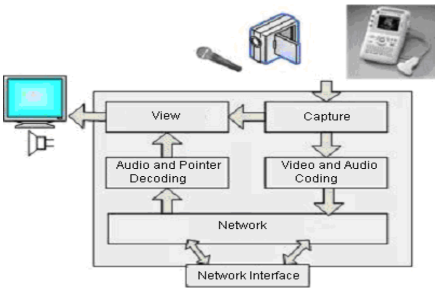

Figure 5: The remote health center system modules.

The system diagram placed at the referral hospital is complementary to the previous one and illustrated by Figure 6. The main differences are that the system codes only audio and pointer. Besides, decodes the remote audio and video, presenting them on the computer screen.

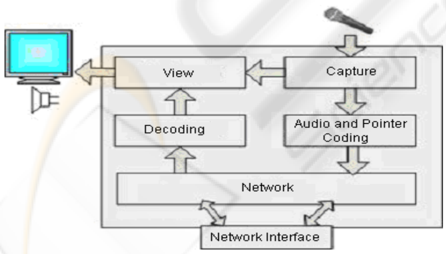

Figure 6: The referral hospital system modules.

5 RESULTS

According to (LeRouge, 2002), any application related to telemedicine with videoconference ought to study the effectiveness of practical requirements in order to reach the aimed system quality. To reach the concern of quality for perceptible fetus movements, some preliminary experiments were performed on 2 CPUs (Dual core Pentium 3.4GHz, 2 GB RAM). The evaluated parameters were:

- Video compression using the codecs MPEG-4 part 2, H.264 and MPEG-2;
- Resolutions of 720x480 and 320x240 pixels;
- 15, 20 and 30 frames per second;
- Bandwidth (bitrate) of 500 kbps, 1 Mbps, 1.5 Mbps and 2 Mbps;
- Audio AAC (Advanced Audio Coding) 64 kbps and 128 kbps.

The H.264 encoder produced good video quality, but demanded high processing power from the computers during video encoding process. Besides that, it increased the total delay to around 1 second and in some condition caused application freeze. MPEG-2 and MPEG-4 encoders resulted small delay (lower than 300 ms). MPEG-4 provided better video quality compared to MPEG-2, being chosen.

Any resolution below 720x480 was considered improper according to the specialist doctor, mainly because of artifacts and pixel interpolation problems detected in the reconstructed video, which could invalidate a correct medical interpretation.

Some experiments changing the number of frame per seconds were also performed in order to define the better relation between frame rate and visual movement video requirements. With 20 frames per second, the result was acceptable, but was better using 30 frames per seconds. Regarding audio, the tests showed to use the AAC codec with 128 kbps, providing a better audio quality.

The experiments were performed changing the overall connection bitrate for audio and video, and the system was tested with 500 kbps, 1 Mbps, 1.5 Mbps and 2 Mbps via PLC. The increasing of the total multimedia (audio and video) bitrate produces better quality; however, it is a limited resource. The best cost-benefit was obtained using 1 Mbps, which was the rate established to the system.

The mean transmission delay was measured with the help of a clock, which was filmed while transmitted, and the overall one-way delay was about 300ms, meeting with communication needs between doctors and being considered real-time according to previous definition.

With these parameters, the case study could accomplish the fetus movements and meet the original need of verifying the heartbeats and breathing movements.

Regarding the pilot at the remote health center, about 40 monthly tele-ultrasonographies were made during a 3-month pilot and the forecast is to increase this number to 600 monthly exams, covering other health centers spread over Porto Alegre. Figure 7 presents the environment at the remote health center, where the resident physician positions the U/S probe according to the doctor's remote guidance. Besides that, it shows the U/S equipment (white, on the table), the video monitor attached to the acquisition computer (behind the U/S), and the video camera that records the transducer and hand of the local physician (behind the patient).

Figure 7: Exam being held at the remote health center.

Figure 8 presents the referral side, showing the specialist doctor at the HPV watching the transmission and guiding the resident physician through audio and using his mouse pointer. From the figure, it is possible to note the U/S screen as well as the small image showing the hand position of the remote physician. The doctor has also a "remote pointer", which uses to show regions of interest commenting by audio.

Figure 8: Remote attendance by the specialist doctor.

During the first month of use, 40 patients were interviewed to collect subjective opinions about their experience. The major advantages mentioned were related to being close to home and the decrease of waiting time to perform the exam (from the original 4 months to actual 1 month). However, this time should decrease, since the statistics considers a number of exams requested before the system started working, i.e., there is a repressed demand which is being minimized at each new exam session at the remote health center.

In addition, the patients reported that did not feel the attendance was impersonal for the fact of interacting also with a doctor located in another place. It is also interesting to mention that the consultations identified, up to now, four cases that required immediate treatment and patient transfer due to bad fetus formation, i.e., it was detected preventively and the forwarding could be well planned.

6 CONCLUSIONS

This paper presented a new tele-U/S system being used not just as pilot project, but it is in continuous use as a pilot service. It connects a poor, distant, and very populated district with a referral hospital located at the city via a hybrid PLC network. The platform was developed by a multidisciplinary team and was submitted to several technological and medical experiments. Final results pointed to the use of MPEG-4 video codec, AAC audio codec, and resolution of 720x480 pixels to achieve the real-time interaction of 30 frames per second. The obtained delay was 300ms, which is better than the 400ms of worst case in the standard of IP videoconferences.

The directly benefited by POA_S@UDE can be sorted in two groups: pregnant patients residing in the peripheral areas of Porto Alegre, i.e., Restinga up to now; and non-specialist or resident physicians, who act in health centers distant from the central area. The benefit for the first group is the reduction of the absences in prenatal exams and the consequent early diagnosis of pregnancy problems. The second group is benefited by the training and constant contact with the specialist doctors from the reference center.

It is important to mention that the number of patients who submitted to the prenatal obstetric exams through the new telemedicine system is still small. However, all the patients who already made the U/S examinations via the platform manifested their contentment about being able to perform the prenatal exams close to their homes, saving transport and being able even to take their other children to the health center. Even more important, the spatial distribution of the exams reduced their waiting time (from 4 months to 1 month) and could now accomplish with the WHO recommendation of 4 medical visits over the pregnancy time. According to the Porto Alegre Health Ministry statistics, this will guarantee an increase at the average ultrasonographies per pregnancy that today, at Restinga, is between 0 and 1, to at least 3 or 4, until the end of 2008.

As future directions, the telemedicine service is expected to be deployed in other neighborhoods or regions distant from the downtown, such as the regions of Guaíba Islands and Lomba do Pinheiro. A "mobile unit" will be equipped with the system, which will be connected to HPV through network points at the health care centers of the covered regions. The unit will be able to transport a resident physician and a computer technician and each new health care center is planned to be attended in one day of the week, reducing the system costs.

ACKNOWLEDGEMENTS

We would like to thank Porto Alegre City Hall at a glance, HPV and Restinga health center physicians, and CEEE (State Company of Electric Energy).

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