Teleradiology on a Personal Digital Assistant

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Abstract: This paper describes the porting of a teleradiology system to a Personal Digital Assistant (PDA). The basis for this formed the CHILI teleradiology and PACS system developed by the Steinbeis Transferzentrum Medizinische Informatik, Heidelberg (STZ) in cooperation with the German Cancer Research Center. The work was done as part of a EU IST project called Multimedia Terminal Mobile (MTM). The authors collected user requirements in a first step. Appropriate hardware has been selected based on these requirements. Dedicated software versions of CHILI have been realized on selected PDA hardware. The prototypes have been constantly evaluated in cooperation with medical end-users. Technologies from project partners like speech communication and speech recognition have been integrated.

Keywords: Teleradiology, mobile computing, Linux, wireless networks, evaluation

1 Introduction

The introduction of small and portable personal digital assistants, mobile phones, and wireless communication in general, has already changed the way we communicate with each other – not only in extreme situations but also for everyday routine communication. This change will also affect the way we communicate in our professional life.

The goal of the authors is to develop mobile teleradiology systems which are independent of stationary and cable-bound computers. This development is based on the existing commercial CHILI (tele-) radiology workstation (Steinbeis Transferzentrum Medizinische Informatik, Heidelberg, Germany) which is the result of a joint project with the German Cancer Research Center in Heidelberg, Germany [Eng97, ESS99].

The mobile teleradiology software uses personal digital assistants (PDAs), pen-based computers or webpads for wireless access to the medical images stored in the archive of a PACS or DICOM compatible workstations. Mobile users are able to receive images from stationary computers, apply basic functions to the images and perform interactive teleconferences with shared (mouse) pointers and synchronized image manipulation functions.

The consortium of the MTM project [MTM01], funded by the commission of the European Community in the IST-Program (MTM IST 1999-11100), was to develop a PDA with special capabilities, such as high speed communication using Universal Mobile Telecommunication System (UMTS), possibility to send and receive audio/video, access to data such as web pages and e-mail. The PDA itself is supposed to be a general tool and not

only be used for medical purposes but also for tourist guides, distance learning etc. To be able to build such a PDA we had to know more about the performance and capabilities that users demand. For this purpose we sent out a questionnaire to medical users (including medical imaging departments) to find out more about hardware requirements of the PDA and application specific requirements.

Based on these requirements the first prototype was developed. Using Linux on the iPAQ PDA helped much porting the CHILI application. Only adaptions according the the special hardware (small display, pen-based user interface) had to be done. The prototypes were constantly evaluated on-site in cooperation with the medical end-users in the project. Lacks in usability and performance could be identified and solved.

2 User Requirements

A questionnaire was distributed to physicians in Spain and Germany to find out the specific requirements for a wireless teleradiology application [BES00]. All physicians work at imaging departments, most of them at radiology departments. 40 physicians filled out the questionnaire. The user group represents a total of more than 400 years of expertise in their respective fields. The most important results were:

- Image size: Minimal image size is 256×256 pixels. Users indicate a typical range of 256×256 up to 512×512 as being very frequent. 12 bit is common. Uncompressed that corresponds to 524 kB per image (12 bits are stored as 16).
- Display: Color display is not required by all. Many gray levels are wanted. Users definitely want the largest display possible, and prefer the larger display in favor of reducing weight. It can be noticed that, in comparison to what's available on the market, users have high expectations on display size and resolution.
- Level/Window: is mandatory. Should perform in seconds or less.
- Compression: Lossy image compression is tolerated, even with visible effects.
- Communication: A 12-bit image of size 512×512 pixels should transmit within 10 seconds, never more than 20 seconds. Users emphasize communication performance, together with display properties, to the extreme. In fact they do not expect the MTM to perform worse than a regular computer in these aspects.
- Input: Pen is preferred. Maybe keyboard for longer types of input.
- Development: Open solutions are emphasized. Users indicate they themselves would like to develop applications which should also run on regular computers.
- Application Scenarios: *"Neuro surgical emergency consultation"* is regarded as the most important application area followed by *"Increased access to senior staff"* as second. Further proposed application scenarios are: *"Bedside access to patient data"*, *"Radiologist in contact with modality"* and *"Access to functional MR specialist"*.

3 Linux on the PDA

First the MTM consortium was supposed to develop a whole PDA but later on the objective was reduced to developing multimedia add-ons to an existing hardware platform. The chosen PDA was the Compaq iPAQ (H3600 series, [Com02]). Some of it's basic features are: Intel Strong ARM processor (206 MHz, no floating point unit), 16-32 MB of RAM, 16-32 MB of flash ROM, 4096 colour (16 shades of gray) TFT display with a resolution of 240×320 pixels. Expansion jackets allow to use PCMCIA and CF-cards e.g. for additional storage and (wireless) network cards. Newer models of the iPAQ (3800 series) provide a built-in Bluetooth module and a slot for secure digital respectively multimedia cards. The iPAQs are equipped with a microphone, a loudspeaker and a stereo headphone jack. Several hardware buttons provide quick access to functions.

The operating system shipped with the iPAQ is Windows CE. In the authors' opinion the greatest achievement of this operating system is that it's hunger for ressources produced such powerful PDAs as the iPAQ is which then can be used sensibly under less consuming operating system like Linux.

The CHILI software was developed and is running under Unix and Linux. It took several man-years to develop the application. Porting it to Window CE would have ment more effort than an EU project could provide. This was a strong point for sticking to Linux. The Linux operating system is very suitable for software development. The software development at the Steinbeis Transferzentrum Medizinische Informatik is usually done under Linux which is another point for using this OS on the iPAQ as well.

Although Linux is not officially sold with the iPAQ there's a lot of support which can be gained from several websites. Maybe the most popular one is `www.handhelds.org` founded amongst others by people from the Compaq Cambridge Research Labs (CRL). They provide a lot of know-how, a mailing list, several Linux distributions and software for the iPAQ. Also a skiff cluster accessible via telnet or ftp to compile software on has been installed by the CRL staff.

The first distributions originated from the Debian and Redhat distributions for the ARM processor. Meanwhile distributions specially designed for the iPAQ are available. New features have constantly been integrated and a lot of hardware is supported.

4 Development under Linux

Most tools needed for development (editor, CVS, compiler, linker, debugger etc.) are available on the iPAQ. In the project a nearly complete Debian distribution was mounted using NFS and the used changing the root to it (chroot). In most cases the applications were compiled natively which is much easier to set up and use than cross-compiling. On the other hand in some cases the resources of the iPAQ fail to compile large and complex packages. Using the large RAM and computing power of a cross-compile host might help in those cases but the chain is quite complicated to install and use. Popular GUI toolkits (X11/Motif and Qt) are also available for the iPAQ.

Figure 1: Interview during evaluation at Clinica Femenia (Palma de Mallorca)

A package manager (ipkg) eases the installation of software. It was also used for CHILI which can be installed in different extents e.g. the IP telephony feature can be left out if it is not needed. A complete Linux installation including a GUI toolkit consumes about 12MB of flash ROM on the iPAQ. The remaining space may be to little to install all features of the mobile CHILI at least on a 16MB system. In contrast to Linux Windows CE can store additional software only in the RAM disc (or an additional storage card) which does not survive a hard reset. Newer models (e.g. iPAQ 3700 and 3800 series) provide more flash ROM and slots for SD/MM cards to extend the storage space.

Porting software to the iPAQ is generally not a great problem. Most applications run immediately after compilation. Of course adaptations of the user interface to screen size and pen-based control might be necessary. The sound hardware shows some oddities e.g. not all sample frequencies are available and the sound is only recorded in stereo mode. Unfortunately the applications dealing with voice recording (speech recognition and IP telephony) usually work with low quality samples (8kHz mono sound) which is not supported. To use them the sound had to be converted first.

5 On-site evaluation

The prototypes developed during the MTM project were constantly evaluated in cooperation with clinical end-users. The results are noted below with the corresponding prototypes. This paragraph describes the evaluation methods. The medical partners in the MTM project were radiology departments on hospitals in Madrid (Sanatorio de Nuestra Seniora del Rosario, department of magnetic resonance), Palma (Clinica Femenia, department of radiology), Nuremberg (Hospital North, department of radiology) and Heidelberg (German Cancer Research Center, department of oncological diagnostics). During the different evaluations up to 10 radiologists and one biochemist were interviewed.

The equipment was installed at the radiology departments. It consisted of a stationary CHILI workstation which was integrated into the radiological environment. Images from various modalities and other radiology systems were transferred to the CHILI workstation via DICOM. The iPAQ was equipped with a wireless network (IEEE 802.11b) card and

an router was installed to connect the wireless and the cable-bound network. The mobile CHILI accessed the database and image of the stationary CHILI workstation.

First the application was demonstrated by the evaluation personal. After this the test person was asked to play around with the application for a while or to perform certain tasks given by the evaluation personal e.g. ”try to find another patient in the database” (see Fig. 5). Afterwards the test persons were interviewed. Questions about their background concerning computer systems and radiology were asked as well as about the application itself. The question were kept quite open in order to avoid influences.

The interviews were recorded on audio tape. Also the surrounding (department etc.), the interviews and test persons trying to use the application were filmed with a video camera. The usage was filmed from the back and in close-up to be able to analyze problems using the application. Due to the evaluation being carried out first in Germany and a few weeks later in Spain the methods and interview guides could be revised with the help of an expert from the University of Uppsala, Sweden. The interviews were shortened and kept more open. No predefined questions were asked but only guiding keywords were given. The small number of participants made a greater effort in favour of more detailed and individual results possible.

6 Prototypes and functionality

6.1 First prototype

During the MTM project several prototypes were developed. The first one still ran on a server with the display redirected to the iPAQ. The whole functionality extent of the normal stationary CHILI system was provided including tools for image manipulation and doing cooperative sessions with synchronized images, functions and mouse pointers. The layout was changed to fit onto the small screen and the user interface was changed to be controllable with a pen. The application used the database and images of a remote server. An image is “sent” to the iPAQ by selecting it on the stationary CHILI system and hitting the “pager” button.

The evaluation results showed that only a subset of the functionality available on the stationary CHILI application is needed in the mobile version, e.g. tools like axes and markers were left out. The method to select the tools (tap&hold) didn’t prove to be a suitable solution. It was clear that the performance had to be increased or that actions like continuous zooming and level/window operations where every step in between is calculated had to be replaced by more discrete ones (zoom in steps or level/window according to a selected area).

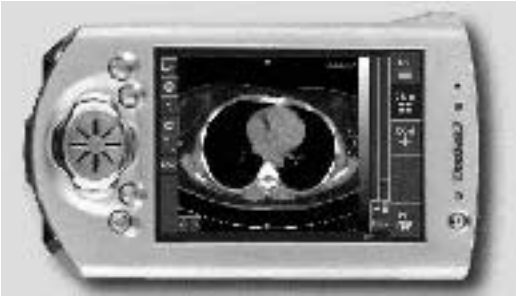

Figure 2: Mobile CHILI application running on the Compaq iPAQ

7 Ongoing development and evaluation

The next prototypes were compiled and run locally on the iPAQ. The functionality was on one hand reduced to only a few quite fast and easy to use tools for viewing (zooming in two steps, panning, magnifying glass) and grayvalue operations (level/window with ROI, presets and autolevel function, measuring of grayvalues). On the other hand functions for navigating within the studies (database browser) and series (lightbox with thumbnails) were added. The feature of a synchronized cooperative session was kept for it is a crucial feature in the desired scenarios. The user interface was revised according to the points mentioned in the evaluation (see Fig. 7). The tools could now be selected directly via software buttons. Another prototype was developed in respect to the outdoor usage of the mobile CHILI. Images can be kept locally and accessed using a DICOMDIR file as a database. Due to the parsing of the images and creation of the DICOMDIR file takes some time on the iPAQ this could alternatively be done in advance on a server and the compressed images including the DICOMDIR file could be transmitted e.g. using secure copy. To gain independence from the CHILI server a DICOM C-STORE SCP can be run directly on the iPAQ. Applications to receive images and to create DICOMDIR files are available.

7.0.1 Speech communication and control

One objective of the MTM project was a strong interaction and integration between the project partners. The mobile CHILI application integrated the IP telephony software from Pointercom, Italy, to enable speech communication with IP telephones or any software client using the standardized H323 protocol. This feature is quite important especially during cooperative sessions. The built-in microphone and speaker provide a quality comparable to a mobile phone. The MTM extensions of the iPAQ provided jacks to use an external headset to increase the sound quality.

Another technology to be integrated was the speech recognition kit developed by the Laboratoire d'Informatique of the University in Avignon, France (LIA). Due to the missing floating point unit the iPAQ's performance is not sufficient to decode the speech in reason-

able time. Even reworking the application by LIA to use integer operations and a special ARM library couldn't change that fact. Therefore a server based solution was implemented where sound is recorded and converted on the iPAQ and sent to a speech server running on a stationary Linux machine. The speech server then interacts with the mobile CHILI application by sending messages with the decoded word or directly faking X-events in the application.

7.1 Good but still not perfect

Evaluation of this prototype evaluation showed that the performance and usability had improved much. The functions were supposed to be fast and easy to use although the use of level/window functions could be improved for the use with MR images (more presets, manual adjustment). The added features like access to a database were appreciated much. The quality and utility of the speech communication were considered good. The voice control of the application was stated to be helpful but could be improved in speed and coverage of the available functionality. Generally the application was considered to be useful in the desired scenarios.

The performance especially when loading a series should still be improved. Several solutions might solve this problem. Instead of using the images meant for a powerful stationary application the mobile CHILI should use a pre-processed set of image which should be adapted in aspects of resolution, colour depth, compression and level/window according to the iPAQ's requirements. The pre-processing could be done on a server before transmitting the images to the iPAQ.

8 Prospect and conclusion

The tasks to be worked on next are to improve the application according to the latest evaluation results. To use the mobile CHILI outside the hospital for background duty fast mobile networks (GPRS and UMTS) have to be integrated. Pre-processing especially with compression has to be done before transmission. Security concerns can hopefully be covered by using tools for virtual private networks which are also available for Linux on the iPAQ. GPRS mobile phones could be connected via Bluetooth to avoid additional hardware extensions to the quite lightweight iPAQ. Integration into a DICOM environment (receiving images from modalities and querying DICOM archives) should be implemented to gain independence from a stationary CHILI system.

Future models with faster processors (e.g. Intel X-Scale), more storage (RAM/flash ROM, storage card slots), improved displays and additional features (built-in GPRS, Bluetooth) might solve many of the problems still apparent.

Linux on the current PDAs is a promising platform. Sophisticated tools for development are available and the community grows constantly. New hardware and features, e.g. Bluetooth, are supported relatively quick.

In conclusion the authors can say that the mobile CHILI is on a promising path to turn into a successful product. The current prototypes will be further developed and evaluated in cooperation with clinical end-users. The application was appreciated much during the evaluation. The utility for the desired scenarios could be proven.

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