Personal Digital Assistant in an orthopaedic wireless ward: The HandHealth project

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\textbf{A B S T R A C T}

Personal Digital Assistant devices are becoming a frequently used device for the bedside care of the patient. Ways of application are many, but limitations are also numerous. Input device and monitor resolution are limited by the device size. Moreover, the choice of specific programs and the amount of storable data are limited by the quantity of memory.

During HandHealth project a system was developed using a different point of view. Personal Digital Assistant is only a means to access data and use functionalities that are stored in a remote server.

Using that system patient ward note can be showed and collected on the handheld device but saved directly on the Hospital Information System. Medical images can be showed on the device display, but also transferred to a high-resolution monitor. Large amount of data can be dictated and translated by remote continuous speech recognition.

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\section{Introduction and background}

Nowadays, Information Technology (IT) is broadly used in healthcare environment. Applications are several and one of them is the ward time management. There are several ways for time optimisation and more and more the answer to these problems are Personal Computers. Today, it is not unusual to find PCs in hospital wards, especially in physicians and nurses offices. Nonetheless, it is still difficult to access patient information during bedside care. This implies gathering information before the ward round and hand writing the note at the end.

Several studies have proposed ways to overcome such a situation via the utilization of handheld technologies (Personal Digital Assistant: PDA). Proposed solutions vary significantly, despite similarities among different devices. Drug information [1,2], access to literature [3], visualization of medical images [4,5], communication to remote physician [5], visualization and writing of clinical report [6–8] are some of the examples available in literature. The use of this kind of technology gives the opportunity to gather information at any moment and place, but also promises to make faster and more secure the everyday ward work.

The studies analysed usually present some common drawbacks, most of which are related to the PDA hardware structure. All PDAs have limited data input devices. Key-pad, virtual keyboard, or handwriting recognition, are the most common methods nowadays available for data input.

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Unfortunately, none of these input ways is applicable for inserting large amounts of written data [9]. PDAs have limited amount of memory, so it is not possible to install several different software in the same device. In some cases even a single software can present problems. For instance, some software could help in data input operation, such as continuous voice recognition, but currently it is difficult to implement a solution with a large vocabulary due to memory limitations [9]. Monitor resolution and size are also limited. For a PDA, in order to be portable, small dimensions are required, which means that the monitor cannot be wider than a few inches. Finally, all data have to be stored inside a handheld device and synchronized. Further on, this reduces the amount of memory. In a single handheld device it is impossible to store all the digital data of a healthcare institute. It is thus necessary to choose a clinical application for every PDA. In this way it is possible to update only data related to a specific application. The data security is another limitation regarding the environment and not the devices. In a healthcare environment, data access has to be secure. Accordingly, strict password protocol must be developed in order to guarantee data security [6].

The HandHealth project was a feasibility study in which we developed a system by using a different point of view. PDA is only a means of data access and functionalities use that are stored in a remote server, in order to make the everyday ward work faster and more secure. We developed a wireless system by using the wi-fi (IEEE 802.11) specifics. In the course of the project a wireless net was realized in an orthopaedic ward of Istituti Ortopedici Rizzoli (IOR, Bologna, Italy). Using that system patient ward note can be collected through a predefined form and than visualized. Medical images can be shown on the PDA display, but also transferred to a high-resolution monitor. Large amount of data can be dictated and translated by a remote continuous speech recognition software. Moreover, security access was guaranteed by the use of Radio Frequency IDentification (RFID) badges.

The aim of the project was to verify the feasibility of a structure in which the services above described could coexist in a handheld device. In this work we describe the system framework developed. Some preliminary findings are shown and the application put into practice in an orthopaedic ward is illustrated.

2. Design considerations

The developed system framework is described (Fig. 1). The PDA can dialog anywhere and any time with the Health Information System (HIS) by means of a web server. Data were directly read and written in the HIS database, no synchronization was needed.

A continuous speech recognition server was used. It was possible to send a maximum of 2 min voice file to a large continuous speech recognition software by using the PDA. The translation was copied in the HIS via web server. Once the translation was copied it was possible to visualize it on the PDA display, so as to apply some fast corrections. A remote work-

Fig. 1 – Main system framework. PDA can access to HIS via a web server and can use remote programs and capabilities stored in the speech recognition server and the imaging one.
station was connected to the web server in order to check the translation. The remote workstation permitted a more comfortable correction environment. The opportunity of listening the dictation file was also available.

A structure for radiographic images display was also realized. PDA communicated with a radiographic server and a preview of the selected image was shown on the PDA display. The previewed radiographic image could also be displayed on a remote high definition monitor, selected by the PDA.

3. System description

3.1. Safe data access

Every user had to authenticate himself in order to access to patient data. Authentication was done by means of a RFID badge. Thirty-two personal badges were distributed to 21 nurses and 11 orthopaedists. User name and personal password were stored in the RFID badge. The used badges were passive, and during the authentication procedure were activated by the PDA. The excited badge could be powered by the emitted radio waves so as to send back the information stored. The range of the RFID antenna was up to 10 cm. Patient data access from PDA was possible only at the end of the authentication procedure and there was no other access way. A remote server checked all the accesses so that in case of badge loss it was easy to change the password.

On acceptance every patient was assigned a barcode. The barcode was printed on a wearable wristlet that was worn by the patient during the whole hospitalisation. Access to all patient data was then possible by reading the barcode from the PDA at the bedside.

3.2. Nurse and doctor records

Different RFID code permitted to recognize different kind of users. Nurses and physicians had different tools, but general data access in common. Both had the possibility of patient personal data and laboratory exams results displaying (Fig. 2).

Nurse ward round was supported by an electronic sheet (Fig. 3). Nurses were able to make a parameter selection of values they wanted to measure before the ward round started. During ward round nurses were able to insert new data directly into the HIS and visualize previous ward round note. Printing report was also possible.

3.3. Clinical image visualization

Orthopaedists were able to preview clinical images on the PDA display. A list of all patient clinical images was shown. A specific image could have been selected and displayed. Despite of PDA display low resolution, the image could have been zoomed-in to enhance specific zone visualization (Fig. 4). This procedure permitted visualization of clinical image anywhere orthopaedists wanted. High-resolution visualization was also

Fig. 2 – HandHealth patient report. The report presents patient master data (a) and laboratory exams (b).
Fig. 3 – Nurse ward round electronic sheet. The electronic sheet present parameter selection (a), data entry (b) and data visualization interface (c).
Every time an image was requested from the PDA a call was sent to the Imaging Server, where a Multimod Application Framework (MAF) Server [10] for radiographic images management was installed. The call result was sent back to the PDA. The same process occurred every time a zoom procedure was requested. The maximum image size transmitted was fixed (223 × 271 pixels × 8 bit ≈ 59 Kbyte). No scrolling bars were present in the visualization window. A pan procedure was implemented. By clicking at one side of the picture, a call to the imaging server was processed and an image, translated into the selected direction, was sent back to the PDA.

All the clinical images were taken from the Picture Archiving and Communication Systems (PACS) of Rizzoli Institute.

A large vocabulary continuous speech recognition software was available. Orthopaedists were able to use speech recognition utility during ward round. A speech file was saved on the PDA and sent to the speech recognition server. The speech signal was sampled at a frequency of 22 kHz and converted in a digital signal using an eight bit conversion. A single channel was used (mono recording). The translation was available in 10–20 s, proportionally to the dictate length. Translation was saved in the HIS via the web server and was then available for PDA display (Fig. 6). Corrections were permitted during the PDA display, but only by means of a virtual keyboard. Every correction was saved directly on the HIS.

A remote workstation for speech recognition correction was arranged to provide more user friendly correction interface. It was possible to sit at the workstation in order to check and correct the speech recognition translation using a more suitable standard keyboard. Moreover, it was possible to listen to the audio file recorded by the orthopaedist during the ward round.

The complete speech recognition data flow is shown in Fig. 7.

### 3.5. Hardware and software used

JAVA SDK 1.4.2.10 (SUN Microsystem, Santa Clara, CA, USA) was used as server-side development tool, and visual studio.net 2003 (Microsoft Corporation, Redmond WA, USA) as client-side development tool. The client-side application used .NET Framework 1.1 and OpenNETCF libraries.

The hardware environment consisted of one PC server, one UNIX DataBase Server, one PC client for RX display and speech recognition control, five PDA for remote access and four Access Point (AP) for 10 Mbps wireless connectivity.

### 3.5.1. PDA client-side

#### 3.5.1.1. Hardware components

A battery powered pocket-sized colour screen PDA (Fig. 8), Datalogic Jet (Datalogic, Bologna, Italy), was used. Wi-fi connectivity was implemented.
Figure 5 – Data flow during clinical image visualization. A request of visualization on the remote workstation is sent to the MAF server.

Barcode and RFID reader were integrated on PDA. A directional microphone was also integrated. Palm device was based on Intel (R) PXA255 processor family design with the ARM v.5TE instruction set architecture and run the Microsoft Windows CE.NET Version 4.20 operative system. 5 Datalogic Jet PDA were used.

3.5.1.2. Software components. A compact client application, called HandHealth Client, was developed using C# and installed on Datalogic Jet PDA.

3.5.2. PC server-side
3.5.2.1. Hardware components. The PC server was equipped with Pentium 4, 1.7 GHz microprocessor and 256 MB RAM.

3.5.2.2. Software components. Four server programs were installed: one for each structure capability.

Web server Apache Tomcat 5.0.28 (The Apache Software Foundation, MD USA) was installed. Communications between PDA and web server were allowed by Axis Simple Object Access Protocol (SOAP) engine Phoneidos mobile speech recognition software (Gruppo Soluzioni Tecnologiche GST, Trento, Italy), was installed for speech recognition. The software was based on IBM Viavoice (IBM Corporation Armonk, NY, USA). The software had a built-in large vocabulary of 50,000 words and was trained using orthopaedics clinical records. A Multimod Application Framework Server was also installed for radiographic images management. MAF is an application framework for rapid development of multimodal applications in computer-aided medicine. The installed program was called HHServer. The system was running Windows 2000 professional Service Pack 4.

3.5.3. PC client-side
3.5.3.1. Hardware components. A workstation with double high-resolution monitor was already present in the ward for clinical images visualization. It was decided to use the workstation as PC client. The workstation was equipped with a double Intel Xeo, 2.4 GHz microprocessor and 1 GB RAM.

3.5.3.2. Software components. Two client software were installed on the PC client. GST Differita was installed on the workstation in order to check, listen the speech audio file, and correct the vocal translation. A MAF client was developed for the remote visualization of radiographic images. The program was called HHClient and it was installed on the workstation too.

3.6. Network
In an orthopaedic ward of IOR a wireless net was realized using AP Cisco (San José, CA, USA). A number of four AP was chosen to cover the ward to better meet our requirements. Wired Equivalent Privacy (WEP) combined to Lightweight Extensible Authentication Protocol (LEAP) was used to guarantee a secure data access. SOAP was used in communication via webserver.

3.7. Database layers
All patient information were stored in the HIS database of Rizzoli Institute. During the present study, the achievement to patient information was possible directly from the PDA by asking to a Unix Oracle Server. The request form the PDA to the Unix Oracle Server was processed by the web server.

3.8. Implementation
The code was divided into two parts, client-side and server-side.

Client code was written in C#, using .NET Framework and OpenNETCF libraries. The stubs for web services were created using wsdl.exe tool, distributed by .NET Framework. The client-side was approximately 12,000 code lines long. Server code was written in Java and the number of code lines was near to 4400. The hours globally spent for code programming were approximately 2600.

4. Status report
During the HandHealth project, a framework with wireless access to HIS was developed. A 2 months demo was realized in orthopaedic ward. Orthopaedists and nurses carried out
362 accesses by using 5 PDA. A barcode was assigned to 197 patients and 1435 nurse reports were obtained. Two-hundred and twenty RX images were available for PDA visualization. Sixty-three vocal reports were saved and translated during the orthopaedists ward rounds. To give a descriptive indication of the demo’s results some data are summarized in Tables 1 and 2.

### Table 1 – Main data related to the ward demo are summarized in the present table

<table>
<thead>
<tr>
<th>Data Point</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of ward demo (days)</td>
<td>59</td>
</tr>
<tr>
<td>Barcode assigned</td>
<td>197</td>
</tr>
<tr>
<td>Orthopaedists and nurses access</td>
<td>362</td>
</tr>
<tr>
<td>Images available for PDA visualization</td>
<td>220</td>
</tr>
<tr>
<td>Vocal report saved</td>
<td>63</td>
</tr>
<tr>
<td>Daily ward records</td>
<td>24</td>
</tr>
</tbody>
</table>

### 5. Lessons learned

The present study aims to develop a novel approach to handheld device integration in healthcare environment. In contrast to the common way of considering a PDA as a portable PC, we developed a system in which PDA was used not only as a means of displaying remote data, but also of using remote functionalities. This approach permitted to access the huge amount of data stored in the HIS of the Rizzoli Institute during the ward round and at the bedside. Problem of PDA memory were completely avoided. It was possible to use software that usually require more computational power or amount of memory than in a common PDA, and without a specific PDA projected software. This was the case of speech recognition and image PDA display.

The use of personal RFID badge guaranteed a secure access to patient personal data. The patient data access was available only by reading the personal patient barcode at the bedside.

#### 5.1. Drawbacks

Wireless connectivity must be carefully designed at the beginning of the study. The simultaneous several users’ access to download information can potentially overburden the net. During the present study we designed the placement of AP...
in order to minimize multiple PDA connections through a single AP. Nevertheless, the amount of data transmitted is about 295 KB, in the worst case of five PDAs calling simultaneously for images display and connecting through a single AP.

All the system was developed as a wireless wi-fi communication structure. It was not possible to display data without the presence of an AP nearby. Due to this kind of structure the whole system was completely server dependent. Like in the most common net structures, data were not available if the server was not accessible.

Due to an administrative choice this study did not take into account drugs management. We know that this is an important field not only for the management staff, but also for ward nurses and doctors. We chose not to include drugs management due to the short time in which the demo was running. Moreover, a study on drugs administration inside the hospital is not easily applicable in a single ward.

During the use of the system, approximately 40 PDA crash events were recorded. We did not have the opportunity to know what exactly caused PDA’s crashes during the ward demo. We checked the whole structure during our laboratory tests and we found some similar crashes, but we could not relate them to a specific task. Crash events are probably related to net connectivity, bounded to the prototypical nature of the selected PDAs.

One last drawback is that our system was completely developed to dialog with the internal HIS of the Rizzoli Institute. Thus, our software cannot be used in a different environment without a previous study of the local information system.

6. Future plans

A system was developed in which PDA was used as a means, not only to display local data but also to access remote data and to use remote functionalities. The system was completely wireless and did not need synchronization. A similar approach was not found in literature. Such a kind of framework permitted real-time access to data stored into the HIS. It also presented the preview of clinical images on PDA display with the opportunity of fast visualization on high-resolution monitor. Finally, a speech recognition structure was available.

Future developments can be many. The barcode use could be extended to the drugs management issue, while RFID could be applied not only as a personnel identification, but also as an object identification tool (for example, in surgical instruments). Vocal report could become the main data input device for PDA.

In standard net structures, data are not available if the server is not accessible. This could be a limitation in a framework of wireless PDAs. We propose to have two twin servers,
or a cluster server, to limit the chance of a server malfunction and to guarantee a continuous activity.

A preliminary analysis of the specific HIS was necessary in order to develop an ad-hoc system. Nonetheless, from our point of view this is a valid solution for better exploiting the potentialities offered by PDAs.

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