A TELEMEDICINE DISTRIBUTED SYSTEM FOR COOPERATIVE MEDICAL DIAGNOSIS

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ABSTRACT

Telemedicine is changing the classical form of health care delivery, dramatically increasing the number of new applications in which some type of distributed synchronous cooperation between health care professionals is required. This paper presents the design and development of a telemedicine distributed system for cooperative medical diagnosis based on two new approaches: 1) a distributed layered architecture specially designed to add synchronous computer supported cooperative work features either to new or existing medical applications; 2) the definition of a methodological procedure to design graphical user interfaces for telemedicine cooperative working scenarios. The cooperative work is supported by a collaborative toolkit that provides telepointing, window sharing, coordination and synchronization.

Finally, we have implemented and installed the telemedicine system in clinical practice between two hospitals, providing teleconferencing facilities for cooperative decision support in haemodynamics studies. This specific implementation and a preliminary evaluation were accomplished under the Research Project FEST "Framework for European Services in Telemedicine" funded by the EU AIM Programme.

INTRODUCTION

Over the last decade, a series of social, political and economic changes in western societies have been influencing the evolution of the traditional health and social care models. Several aspects make it necessary to revise current concepts of the means to provide health care, making extensive use of the present state of information and telecommunications technologies; namely: demographic changes, increased health costs, need to improve the quality of medical care, fulfillment of social equity, and opening of new markets.

Telemedicine, a fundamental pillar of that IT&T supported health care, can be defined as the flexible, easy and rapid access to shared and remote medical expertise and resources by means of telecommunications and information technologies, no matter where the patient, the relevant information or the resources are located [1].

The need for computer-supported cooperative work (CSCW) [2][3][4], and particularly for synchronous cooperation, become a fundamental generic service common to many Telemedicine applications whenever a group of professionals wishes to collaborate simultaneously to achieve a common final goal.

Distributed medical communication systems have been developed to provide medical care and education services between remote hospitals. Some of them allow specific cooperative medical applications [5][6][7]. Very few experiences involving general multimedia CSCW architectures for medical consultations are reported [8]. All these research experiences are usually envisaged to make extensive use of broadband network facilities.

This paper presents a general distributed architecture for computer-supported cooperative working tools, designed to support synchronous cooperation tasks, especially suitable for Telemedicine applications. The other critical component which conforms this type of application, the graphical user interface (GUI), is also presented, mostly addressing the definition of a methodological procedure to design GUIs for Telemedicine cooperative working scenarios.

Figure 1 shows the general scenario: the medical teleconference for cooperative diagnosis. The communication service that supports the CSCW is based on any existing metropolitan or wide area network (MAN/WAN).

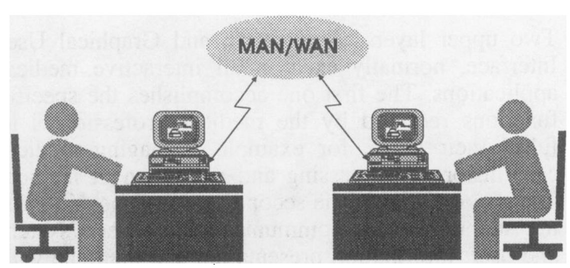

Figure 1. Synchronous Medical Teleconference

The proposed architecture has been implemented in a real pilot to allow both validation of the technology and assessment the usability of the system. A cooperative work scenario for haemodynamic studies was selected.

THE CSCW LAYERED DISTRIBUTED ARCHITECTURE

The architecture for synchronous groupware can be centralized or distributed [10]. In the case of centralized solutions, the application and its data are located at a single site. The application maintains links with several displays so that all the participants have the same view of the system. The main problem with a centralized architecture is the communication and processing bottleneck produced when the application has to attend to the different displays. It also involves additional inconveniences such as its low tolerance to errors.

Our distributed architecture replicates the application code and data at both user sites: two application instances are thus created. The internal structure of these instances is shown in figure 2, where we can see the layered software structure and common data (those needed by both user professionals in order to work in a cooperative manner). This architecture is thus arranged to isolate functions within layers and to achieve a high degree of independence between the functions supported by the collaboration tools and those specific to the application. This approach permits any medical application, based on a window system, to operate directly in multi-user mode without substantially altering the existing code. Below, we describe the layers in terms of their functionality and the protocols of information exchange among them.

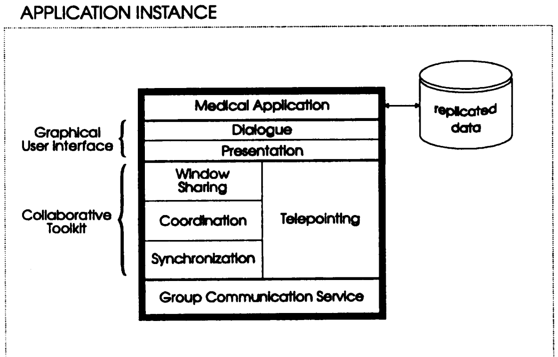

Figure 2. Layered Structure in Application Instances

Two upper layers, Application and Graphical User Interface, normally exist in all interactive medical applications. The first one accomplishes the specific functions required by the medical professionals to fulfill their goals, for example, managing medical case histories, processing and animation of medical images, and so on. The second one is responsible for the support of the communication between system and user: information presentation and dialogue with the medical user.

The Collaborative Toolkit provides synchronous cooperative functions in a transparent manner to upper layers. These functions are telepointing, window sharing, coordination and synchronization. The synchronization function allows the tasks of the application to start and finish at the same time at both sites, preventing problems derived from differences in the processing performance of a specific workstation. The coordination function enables the control of the medical professionals' interactions with the computer system; thereby, at a given moment, only one of them can interact with the cooperative application. This application control is activated by the system, rather than by the user, in a manner referred to as a coordination technological protocol. The window sharing function automatically allows WYSIWIS implementation. Finally, the telepointing function forwards each user pointer to the remaining screens [9].

The Collaborative Toolkit provides utilities that enable the applications to select the windows to be shared. Other functions allow the application to signal the beginning and end of user actions, thus ensuring coordination and synchronization. Internally, this Toolkit picks up all the events produced in the shared windows, subsequently transmitting them to both local and remote applications. Communication between the Collaborative Toolkits is achieved by means of an internal protocol based on token-passing that determines which user has permission to actively participate at a given moment. This technological protocol, unlike sociological protocols, conceals the activity of the moderator from the user during the cooperative work session.

The Group Communication Service allows communication among different application instances [10]. This layer has to support the session joining and exiting operations and both group and single message sending, as well as message consistency and sequence supporting. In our case, it is based on Sun ToolTalk [11], a communication service that links different applications. Although this service assumes a very limited number of message exchanges between application instances and, thus, is not appropriate for hard real-time systems, it is entirely suitable for our cooperative system because our layered distributed architecture minimizes the message exchange between application instances.

USER INTERFACE DESIGN METHODOLOGY

The design procedure of GUI's with high *usability* [12], suitable for systems that support cooperative work between health care professionals, was developed taking into account the results and recommendations of certain research projects [13][14], the state of the art in the area of tools for the development of *GUI's [15]*, and the experience of our research team [16].

The main steps of this methodology, repeated in an iterative cycle, are as follows:

1. Product description. The Telemedicine Service capabilities and features and the information architecture must be described in a structured way (by filling out a questionnaire).

2. Context of use description. To produce user requirements, also in a structured way, a *Context of Use Questionnaire* must be completed including: descriptions of the system users, the user tasks to be performed with the system, and the physical, technical, and organizational environment in which the system is going to be used [16].

3. *Task analysis.* A hierarchical task analysis is performed to assist the functional specification. It consists of the decomposition of user tasks (also referred to as *objective tasks*) into simpler sub-tasks identifying the hierarchical structure.

4. *Enabling task analysis.* In order to allow a complete functional specification, the *objective tasks* must be decomposed into smaller fractions, which are called *enabling tasks* because they allow the user to access the specific system capabilities [17].

5. *Functional specification of the user interface.* A *State Transition Network* is produced taking into account the decomposed tasks (objective and enabling) and preserving the possible parallelism between them. *State* defines the group of tasks that can be performed by the user at each moment.

6. *Specification of the user interface metaphor.* A system metaphor must be selected to show a coherent view of the system to the users, taking into account their previous knowledge, to simplify the cognitive complexity of the system.

7. *Specification of man-machine dialogue.* In this stage, we select the interaction procedures and the dialogue style according to the selected system metaphor.

8. *Specification of graphical scenarios.* Keeping in mind the system metaphor, a graphic representation must be assigned to each of the simplest tasks after decomposition. Each system state (group of tasks) is then converted into a graphical scenario (group of graphical representations of tasks). The transitions in the *State Transition Network* define the transitions between graphical scenarios.

9. *User interface development.* The graphical scenarios should be implemented with a *User Interface Management System* (*UIMS*), observing general design guidelines with respect to dialogue, general screen layout, colors, etc., and specific guidelines concerning system functionality.

IMPLEMENTATION EXAMPLE: COOPERATIVE DECISION MAKING IN HAEMODYNAMIC STUDIES

Medical problem

To implement and validate the proposed general architecture, we have integrated it into an existing application developed within the European Research Project FEST- "Framework for European Services in Telemedicine" (EU funded, AIM Programme). The final goal of this application is to provide a cooperative decision-making telemedicine service to be shared among several regional hospitals and a specialized haemodynamics center. Haemodynamic studies were selected since they require medical personnel and equipment that is affordable only to major hospitals. Smaller clinical sites send their patients to the corresponding referral hospital for an angiographic study. In routine clinical therapy, patients requiring therapy (e.g. angioplasty, atherectomy, valvuloplasty,...) visit the referral hospital twice, where they undergo two catheterization sessions, with all the associated risks, plus additional inconveniences: extended hospital stay, twice the personnel and material costs and reduced catheterization service yield.

Telemedicine CSCW services are intended to contribute as follows: after viewing the just acquired images of the patient, the referring cardiologist could discuss the case with the haemodynamist, consultation that would help in arriving at a diagnosis and deciding the most convenient therapy in "real time"; that is, while the patient is still in the catheterization laboratory and surgical treatment is still possible. The timing constraints for this operation (less than 30 minutes) are very strict.

Additional tools and services complete the CSCW service in the Telemedicine scenario described above: image import from the digital angiography equipment, image transmission, case study handling tools: static and dynamic image viewing and voice communication.

User interface design

Here we deal only with the most relevant decisions taken during application of the user interface design methodology to the medical problem depicted above.

- In order to adapt the system to the *Context of Use* of the cooperative diagnosis, it was decided to implement a telepointing device with no type of dialogue control, assuming both users are at the same level within the organizational hierarchy (as was also described in the *Context of Use*).
- The main objective tasks established at the first level of hierarchical decomposition consisted of: a. identifying images of interest; b. viewing and animating images; c. showing images and animation to another physician; d. speaking with the other physician; and e. cooperating in the diagnostic decision.
- The main *enabling task* is the *image transfer task* which must be performed before cooperative viewing because the system does not support it in real-time.
- A real world metaphor was selected, designed on the basis of the physicians' routine work and the real objects they used; this selection also took into account the users' description in the *Context of Use*: the users had no experience with workstations or with any kind of window environment, and very limited experience with information systems.
- The most appropriate dialogue style for a real world metaphor is direct manipulation of graphical objects, which are, in this case: *box file* (patient information), *wastebasket*, *film tapes* (medical images), *telephone, phone list, television, postbox*, and *box to be sent by post*; the latter two objects are used to perform the enabling task mentioned above, in such a way as to be compatible with the metaphor selected.

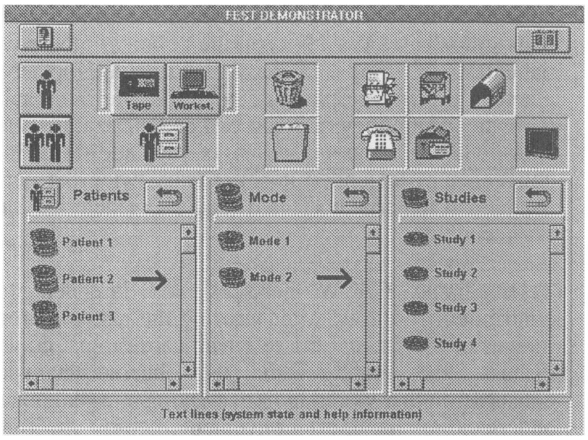

Figure 3. User Interface Main Screen of the FEST Application

Figure 3 shows an example of the user interface for the main screen of the FEST application which was developed with a User Interface Management System (UIMS) for Motif Toolkit. The upper section of the screen displays the real world objects that the physician will use to perform the diagnostic task. This section is equipped with buttons to select actions, such as retrieving data from the digital imaging system, storing data in the backup tape and switching between local and cooperative work. The middle section of the screen consists of *handlers* with the content of the *patient's box file* (*image tapes*), finally showing the *study tapes*, which can be moved within the *television* object to display the medical images. The user interface is completed with a *help* button, an *exit* button in the upper corners and a text line in the bottom section to show the system state and some permanent help information.

System Implementation

The CSCW distributed system was developed in two stages. First, a local medical workstation, based on the X-Windows system and the OSF/Motif toolkit, for decision making in angiography was fully implemented in the specialized center. It was designed with no additional specification for coping with its further integration into our distributed architecture. Second, this local system was integrated on the basis of the Collaborative Toolkit and the Group Communications Service.

A communication network was set up to support all components of the FEST application installed between two clinical sites (30 km apart): Hospital General Vall d'Hebrón in Barcelona (HVH) as the referral site and the Hospital de Manresa (HM) as the referring site.

As illustrated in Figure 4, the network infrastructure consists of:

- A Local Area Network at the HVH site, used to import image series from a Philips digital imaging system (DCI) to the demonstrator workstation (DWS) where the medical application is running. It also allows the DWS to access the remote bridge, as will be described in the following paragraph.
- The link between HVH and HM demonstrator workstations was initially a leased line at 64Kbps using synchronous V35 modems and high speed remote Ethernet bridges with real-time hardware compression; in addition, an ISDN 2B+D link for 128Kbps operation is currently being installed.

Remote bridges are used to allow an Ethernet extension, transparent to all application nodes. Moreover, the use of TCP/IP provides a virtual and safe local area network between the two clinical sites.

RESULTS

The FEST cooperative medical diagnosis system is currently installed and used in clinical practice to link the two Spanish hospitals mentioned above. The results of a preliminary system evaluation [19][20] in real clinical sessions have shown:

- The appropriateness of a technological coordination protocol in this type of cooperative diagnosis applications where time is critical, and users have to focus only on the main tasks supported by the diagnosis application, remaining unaware of the coordination issues.
- Users did not perceive any significant delay in telepointing and in the other synchronous collaborative functions. When compared with other existing centralized architectures, our CSCW distributed architecture optimizes the message exchange between application sites, allowing its implementation on low bandwidth communication lines.

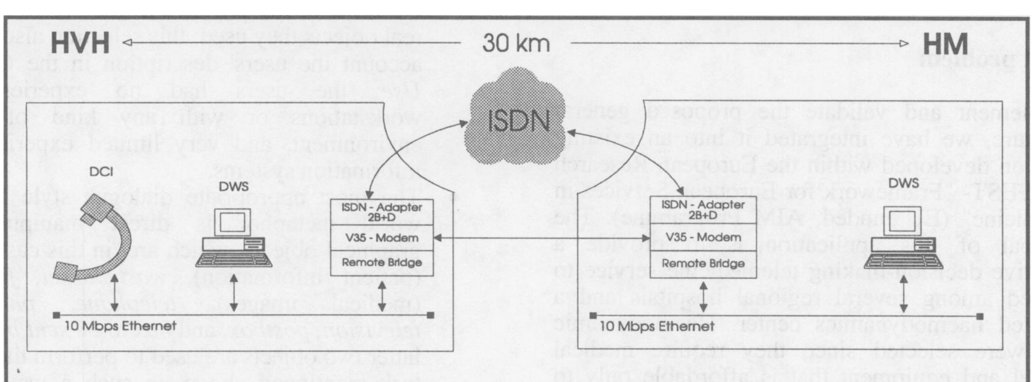

Figure 4. FEST Network Infrastructure

- The feasibility of our design and development approach to cope with the addition of synchronous cooperative working features to an existing local medical application. First, the system was developed in two separated stages with no relevant integration problems, as described above. Second, due to the user interface consistency for both local and telemedicine cooperative applications, the adaptation of regular users to the synchronous CSCW service was very efficient.
- The capability of the user interface design methodology to minimize the number of user interactions necessary to reach a cooperative diagnosis, and to drastically reduce the system learning time.

CONCLUSIONS

The need for synchronous cooperation is essential in many information technology applications where groups of professionals collaborate simultaneously to achieve a common final goal. This situation is especially relevant in Telemedicine services and applications.

This paper has presented a layered Telemedicine distributed architecture to define and implement the main functions of a cooperative distributed and synchronous application. These functions are clearly separated from the application and network infrastructure and provide mechanisms for their implementation in the different existing window systems.

The other critical component which conforms this type of applications, the graphical user interface, was also addressed, with the definition of a methodological procedure to assure the usability of the system.

Finally, we have carried out a real clinical implementation to demonstrate and validate the advantages of new architectural and methodological approaches to the design and development of telemedicine distributed systems for cooperative medical diagnosis.

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