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Holistic approach to design and implementation of a medical teleconsultation workspace

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ABSTRACT

While there are many state-of-the-art approaches to introducing telemedical services in the area of medical imaging, it is hard to point to studies which would address all relevant aspects in a complete and comprehensive manner. In this paper we describe our approach to design and implementation of a universal platform for imaging medicine which is based on our longstanding experience in this area. We claim it is holistic, because, contrary to most of the available studies it addresses all aspects related to creation and utilization of a medical teleconsultation workspace.

We present an extensive analysis of requirements, including possible usage scenarios, user needs, organizational and security issues and infrastructure components. We enumerate and analyze multiple usage scenarios related to medical imaging data in treatment, research and educational applications – with typical teleconsultations treated as just one of many possible options. Certain phases common to all these scenarios have been identified, with the resulting classification distinguishing several modes of operation (local vs. remote, collaborative vs. non-interactive etc.).

On this basis we propose a system architecture which addresses all of the identified requirements, applying two key concepts: Service Oriented Architecture (SOA) and Virtual Organizations (VO). The SOA paradigm allows us to decompose the functionality of the system into several distinct building blocks, ensuring flexibility and reliability. The VO paradigm defines the cooperation model for all participating healthcare institutions. Our approach is validated by an ICT platform called TeleDICOM II which implements the proposed architecture. All of its main elements are described in detail and cross-checked against the listed requirements. A case study presents the role and usage of the platform in a specific scenario. Finally, our platform is compared with similar systems described into-date studies and available on the market.

1. Introduction

Continuous progress in medicine has been ongoing for many years. Among its signs are rapid improvements in the accessibility of medical imaging equipment and, at the same time, increasing accessibility of imaging procedures. According to [1] over 100 million radiographs, 26 million MRIs and 30 million CT/PET examinations are performed annually. On the other hand, the number of medical experts able to properly analyze such scans is growing at a much slower pace. To work efficiently, hospitals are often organized into larger structures, with various levels of reference based on their excellence in specific areas. Routine cases are usually treated at low-reference medical centers while more difficult ones require referral to high-reference institutions.

Teleconsultation applications play an important and well established role in this ecosystem, allowing experts from leading medical centers to remotely diagnose complex cases and suggest proper treatment options. ICT progress has enabled such systems to be applied in everyday medical practice in many countries. Most of these systems operate under a fairly simple rule – their role is to transfer digital medical documentation from one medical center to another and return a diagnosis or further treatment suggestions. Such systems generally allow users to remotely access and analyze medical images and their associated documentation. Due to lack of interactivity this cooperation model does not accurately mimic a real-life medical council. Moreover, simple features are insufficient when complex or atypical cases need to be handled.

Performing effective remote medical imaging consultations remains a real challenge. For over ten years we have been

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popularizing the idea of collaborative remote medical consultations (an example of so-called Computer-Supported Cooperative Work (CSCW) systems) where many users concurrently participating in a consultation session are able to share a view of the session as fully as possible. In our opinion this approach mirrors the traditional consultation process performed locally in the most accurate way. Moreover, it also creates the basis for development of new, more sophisticated applications.

Paul's interesting paper [2] analyzes teleconsultation systems from the standpoint of knowledge management. The author introduces several classes, ordered by growing complexity: systems dedicated to (a) knowledge transfer, (b) discovery, and (c) creation. Typical teleconsultations rely on simple knowledge transfer. An example of the knowledge discovery class is provided by the formulation of a new diagnosis. The rarest cases involve knowledge creation – e.g. invention of a new disease treatment protocol. We believe that challenging scenarios require appropriate telemedical infrastructure and that collaborative teleconsultation systems provide the proper means to tackle them in an effective manner. Even though a convenient way of communication is provided, in many cases the cooperation flexibility is indispensable. Statically deployed structures (spokes connected to a single hub – usually a university-affiliated medical research center) with applications running on predeployed machines are not able to cope with requirements of urgent and rare cases which call for dynamic on-demand creation of teleconsultation services, possibly with an international scope.

In this paper we describe our approach to the design and implementation of a universal system for imaging medicine. We believe that our proposals are justified by our longstanding experience with development, deployment and monitoring of various scenarios in the TeleDICOM I [3] interactive teleconsultation system. The presented concepts are embodied by TeleDICOM II, the successor of TeleDICOM I. We consider various scenarios related to medical scans: individual assessment, multiparty non-interactive and interactive remote consultations for diagnostic and research purposes, efficient handling of medical conferences and workshops, as well as teaching and training – thus satisfying all three conditions listed by Paul.

Our aim was to design a modern, flexible and extensible telemedical platform, which could be easily adjusted to the needs of specific deployments – to achieve these goals our system design follows the Service Oriented Architecture (SOA) principles. Potential users of the platform include doctors, medical students and researchers, as well as small, medium and large healthcare centers. Cooperation is performed in a secure environment called a Virtual Organization (VO) – these can be created on demand, taking into account specific needs of the target community, and be isolated from other VOs.

Practical implementation of such a system is technologically challenging. Interactive communication is characterized by strict Quality of Service (QoS) requirements, especially when conducted between multiple participants in a heterogeneous network environment. Other important aspects include scalability, security as well as construction of a universal and user-friendly Graphical User Interface (GUI), to mention just a few.

As the merit of our approach we attempt to address all the issues related to creation of medical teleconsultation workspace in a comprehensive way. We take into account a very wide range of usage scenarios – adoption of the collaborative cooperation model makes it possible to perform virtually any activity related to medical imaging data independently or in groupware mode. We propose a sophisticated, flexible and scalable architecture and discuss implementation issues multi-dimensionally. Therefore we can claim that our approach is holistic.

The structure of this paper is as follows. The state of the art in the target domain is presented in Section 2, alongside our to-date experience. In Section 3 we discuss our holistic telemedical workspace model. Section 4 describes the architecture of TeleDICOM II which satisfies most of the stated requirements. Section 5 presents selected implementation aspects. Case study in Section 6 describes typical scenarios of TeleDICOM II utilization. Section 7 ends the article with conclusions and a description of future works.

2. Background

2.1. State of the art

Many medical teleconsultation systems have been created over the years. As described in detail in the following sections, several aspects have to be considered when designing such a system. We propose to divide these aspects into four categories, each of which will be thoroughly discussed later on in this paper: (a) application-level usage scenarios, (b) user requirements, (c) organizational issues, and (d) infrastructure.

In the scope of application-level usage scenarios the main criterion is the communication model. While many systems offer simple asynchronous, store-and-forward capabilities [4–14] more sophisticated solutions enable synchronous consultations based on audio, video and chat channels [15–24]. Advanced systems offer interactive tools such as whiteboards, telepointers and (in fewer cases) synchronized annotations and image processing capabilities [25–37]. Our solution enables full view synchronization including an extensible measurement toolset, and provides multi-access control with fine granularity (down to the level of single objects and operations).

The second relevant aspect in this category is the purpose of the teleconsultation session: diagnostics, research or education. While diagnostics are the primary focus of most of the presented systems, research and education are rarely taken into account and supported in an enhanced manner [4,10,20,38]. Our system provides multiple cooperation modes suitable for each of these scenarios.

User requirements include (among others) image transformations, annotations, measurement tools and data presentation tools. Basic image transformations are available in most systems. Annotations and measurement tools are common in asynchronous systems [8,11,16,29,30] and less common in interactive synchronous systems [36,37]. Many solutions focus on one area of medicine, providing specific tools only for one field, e.g. teledermatology [11] or telecardiology [12]. The issue of extensibility and adaptability is rarely addressed [39,40]. Our solution provides a wide range of synchronized tools for image transformations, annotations and measurements which can be easily extended (including synchronization) in order to adapt the system to any medical domain. We also support data presentation by enabling multiple views and sorting features. Finally, we provide image processing optimization – an important aspect of interactive scenarios which is seldom taken into account [41].

Organizational issues are related to formal aspects of creating a cooperation workspace which spans multiple healthcare providers. These issues are conveniently omitted in most papers, with few exceptions in some of the more recent works [42–47]. Here, we identify several aspects, including multiple, isolated cooperation networks, resource allocation, security, fine-grained user permissions and non-repudiation. In order to address these issues we employ the concept of **Virtual Organizations (VO)**, which is only acknowledged in a handful of telemedicine-related publications [42,47]. Our solution facilitates creation of new VOs and enables convenient participation in multiple VOs.

As stated in our previous papers [48,49], proper infrastructure is one of the key prerequisites of an advanced teleconsultation