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Abstract

Objective. – The ultimate goal of the Syseo project is to create a chain of collaborative processes to allow the hepato-gastroenterology endoscopy specialist to manage images easily.
Methods. – A field study has been done to better understand and formalize practices and contexts of use. Based on these results, we have designed tools for gastroenterology, tackling several domains of computer science and reusing well-known format or concepts especially DICOM files, semantic retrieval and infocus-breakpoint.
Results. – Syseo consists in four main components: (1) a data management system relying on the well-known standard DICOM format; (2) a polyp ontology and description logics to manage gastroenterological images; (3) software to estimate the size of a neoplasia from colonoscopic images and (4) pearly user interfaces to enhance collaboration.
Discussion. – Preliminary results of Syseo are quite promising since the proposed solutions enable to efficiently store, annotate, retrieve medical data, while providing relatively accurate measuring tools for physicians and medical staff.

1. Introduction

Up until recently the specialities, which claim to be from medical imaging resulted mainly from radiology techniques shelves. Thereby, for the last 10 years, the focus was essentially on the setting up of interpreting and storage units software's stations for heavy equipment (MRI, SCANNERS). The value of these solutions is related to the high price of the connected appliances and the generated gains by saving on films. This strategy of the rollout predominantly centred on public hospitals ended up penetrating sharply the private companies in reference to the government incentives to archive the patients' radiological films and to swap to digital only. This measure is still relevant today and it brings a real work comfort for the radiologic technicians, and ultimately for the radiologist himself.

The non-radiological images and video and the use of these are more gruelling in some specialities such as digestive endoscopy where the image is acquired, interpreted and used directly by the doctor in real time and without the help of manipulation. This "real time" operating mode makes tough the setting up of tools for acquisition or images scattering: a global solution, all in one, only could allow their emergence in operating theatre.

The Syseo project aims to create a chain of collaborative processes to allow the hepato-gastroenterology endoscopy specialist to produce new images, archive, annotate and retrieve them easily, providing in addition computer vision tools, especially to estimate measures. The software ergonomics and the use of new devices must take into account the context of use in order to extend, on one hand, the span of an examination, improving the quality of the treatment, on the other hand.

2. Method and material

The Syseo project aims to create a dynamic workflow to enable endoscopy specialists, particularly in hepato-gastroenterology, to easily manage images. In partnership with gastroenterologists, medical practitioners and medical IT experts, we defined a two-fold approach to drive this work. The first step consisted of a field study to better understand and formalize medical practices as well as contexts of use of health care applications. It leads us to produce formal representations of medical practices and contexts of use. Based on these results, the second step consisted in designing tools for gastroenterology. Still in partnership with gastroenterologists, this step leads us to identify new needs and requirements.

In order to understand medical practices in gastroenterology and to identify the different contexts of user interaction with healthcare interactive systems, a thorough study of the field has been conducted in three phases:

- meetings with doctors and secretaries;
- analysis and modelling of their needs;
- validation of this work with different actors.

The rest of this section introduces the background of this work, namely the DICOM standard, semantic retrieval and infocus-breakpoint.

2.1. *DICOM standard*

DICOM standard (http://medical.nema.org) aims to make it possible interoperability between medical imaging systems, especially to make it easier exchange of medical data. DICOM file has a hybrid structure that contains regular data (patient/clinical information), multimedia data (images, 3D volumes, video, waveform, graphics), and services (store, print).

Data inside a DICOM file is formed as a group of attributes. Each attribute is defined by a label and the length of its content. A label is represented by two hexadecimal numbers: the first is the group number (0010 for patient group) and the second is the element number (0020 for patient id).

2.2. *Semantic image management*

The semantic approach is based on an ontology of the domain [1], that is a dictionary where words (referred as concepts) are given a definition, expressed with other concepts having themselves a definition, and so on. Our ontology thus models the colorectal polyps domain, as a first step towards the entire gastroenterology field. Its concepts are used as keywords to annotate polyp images and to express image queries. Three main kinds of annotations are available: image observations, polyp classifications and suspected diseases. To annotate their images and to express their image queries, practitioners navigate through a tree interface to choose the right concepts. This interface is intuitive showing only the concept names and not their definitions. Since it is based on these definitions, the underlying automated retrieval process is said to be semantic. It consists of logical inference techniques called reasonings which make it flexible, since relevant images can be retrieved even if not annotated with the same concepts as the query ones.

2.3. *Using blur to estimate depth*

Syseo exploits image blur to estimate a neoplasia's size. A detailed presentation of our system can be retrieved in [2]. This uses two key relationships. The first one, R1, exists between the distance d from the colonoscope to the neoplasia, the neoplasia's size in the image (in pixels) and the neoplasia's real size s (in mm). The second one, R2, exists between the level of image blur b (also called 'defocus' or simply 'blur') and d.

Both R1 and R2 are well known in the computer vision literature. R1 may be easily understood from a simple geometric reasoning: as a consequence of the law of perspective projection, the closer to the colonoscope a fixed size neoplasia, the larger its image. R2 on the other hand is a natural consequence of the colonoscope focusing at a focusing plane lying at a predefined distance f. The neoplasia's image is sharp for $d = f$ and is blurred otherwise. It has been shown that R2 can be modeled using geometrical optics.

Using blur to estimate d is not new. This was exploited in the so-called shape-from-focus and shape-from-defocus methods [3]. The former extracts the sharpest image from an image sequence with varying imaging parameters. The latter uses two or more images with different optical settings to infer d. Both methods tend to be unstable in colonoscopy for the colonoscope's images tend to be focused for a wide range of distances: finding the sharpest image (for shape-from-focus) or the blur discrepancy (for shape-from-defocus) is thus unstable. Syseo resolves this problem by introducing a singular point in the blur-to-depth relationship: the infocus-breakpoint.

3. Results

Fig. 1, overview of the Syseo system, gives an overview of the global system consisting in four main components:

- a data management system which makes it possible to produce and store high definition images and videos in the DICOM format to be massively store relying on the cloud computing paradigm;
- a polyp ontology to annotate these documents and provide an efficient retrieval process;
- post processing tools to enable to measure the size of neoplasias from images;
- in order for the system to be used in several contexts, in several places (an hospital, a physician office or an amphitheatre during a lecture or a conference) and by different of users (physicians, nurses, students, etc.), using plasticity design and enhancing collaboration with pearly user interfaces.

3.1. *Data management system*

We propose a hybrid (row-column) two layers data storage structure:

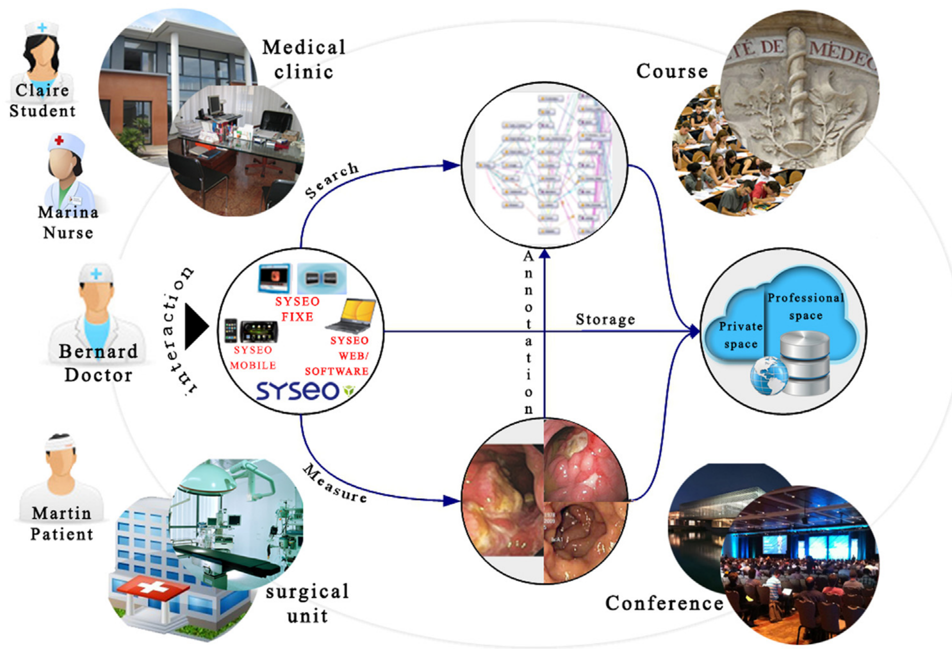

Fig. 1. Overview of the Syseo system.

- to manage high degree of heterogeneity of DICOM files;
- to store large amount of data;
- to enable data to evolve to match new versions of the standard. Both (row-column) layers are cloud-based, which ensures the elasticity and fault tolerance for each of them. Another important aspect is a good level of normalization of data for each layer to reduce the storage cost.

We propose to store mandatory/frequently used attributes and the frequently together attributes in a row-oriented database layer to improve the query execution time, by minimizing the tuple reconstruction time. The advantage of this layer is its write-optimized feature (each tuple insertion in row-oriented databases needs one disk block I/O for insertion alone). Thus, having a lot of inserts over this layer will not be challenging.

Optional/private attributes vary enormously from one medical file to another and from one medical center to another. To manage heterogeneity, we propose storing them in column-oriented databases. Only non-null attributes values will be inserted into their corresponding columns. This layer offers the ability to perform efficiently ad-hoc/statistical queries. Additionally, the physical structure of these systems provide a good solution for the evolving schema issue, since each column is stored in a separate disk block.

3.2. *Polyp ontology*

Grounded on the ontology and the associated annotation interface presented in section 2.2, the semantic search of polyp images is achieved by three reasonings. These are inference techniques based on the description logics formalism [4] and the OWL web ontology language (http://www.w3.org/2007/OWL). The first (R1) is the classical individual retrieval reasoning (here individuals are polyp images): given a polyp classification (resp. an image query), it finds all the images which annotation logically implies the classification (resp. the query). The second reasoning (R2) is the exact classes retrieval: given an image annotation, and the name of a classification, the issue is to find the exact subclasses this annotation belongs to, i.e. the subclasses which all definition properties can be inferred from the input image annotation. The third reasoning (R3) is the approximated classes retrieval: given an image annotation, and the name of a classification, the issue is to find the approximated subclasses this annotation belongs to, i.e. the subclasses from the definition of which we can infer all the properties of the input image annotation. An interesting point with the previous reasonings is their composability. For example, combining S1 after S2 allows to retrieve all the reference image annotations that belong to the exact classes of an input image annotation.

3.3. *The infocus-breakpoint*

The Infocus-Breakpoint corresponds to the shortest colonoscope to neoplasia distance on the edge of the focusing range. This is usually a quite short distance, of the order of a few millimetres. This distance can be first precalibrated, and is then used *in vivo* for interactive neoplasia size estimation using R1 and R2, as explained directly below.

We have developed an infocus-breakpoint estimation module. Given a short video, this module tracks a region and computes its infocus-breakpoint automatically. Our system may be used after calibration of R1 and R2 has been carried out.

The goal of calibration is to recover the parameters involved in R1 and R2. Calibration is carried out only one time and preoperatively. It consists in moving a calibration apparatus such as a checkerboard in front of the colonoscope preoperatively.

The structure of the calibration apparatus is known to a good accuracy, and makes two things possible:

- we can calibrate the colonoscope's geometric properties, this gives R1;
- we can estimate the calibration apparatus's distance to the colonoscope at the infocus-breakpoint, this gives R2.

In the intraoperative course, the gastroenterologist manually marks a neoplasia using a computer's mouse. Our system tracks it while the colonoscope is moved around the neoplasia, and finds the infocus-Breakpoint, from which R1 and R2 may be exploited on a selected image. This allows the gastroenterologist to obtain a size measurement by clicking on one of this image.

3.4. Pearly UI

In order to foster the collaboration among practitioners and to take benefit from the knowledge of diseases in families, Syseo promotes social relationships as key for improving care quality. It investigates the Pearls, a cloud-oriented user interface metaphor that embraces the key characteristics of cloud computing: big data, on-demand services and the convergence with social computing.

At a conceptual level, the metaphor switches from classical core entities (data, actor and task) to socially augmented entities (SAE) enhancing their inter relationships (data-actor, data-task and task-actor) in order to integrate the social dimension into a service-oriented user interface.

Pearls are means for revealing the relationships between entities. A Pearl is a heterogeneous collection of actors, services and data. It is an edge of a hypergraph whose vertices are elements of a set that is itself the union of three sets of core entities (actors, services and data). Such a graph represents a partial view of actors' social network and thus highlights the social work of actor entities, as the fictive socio-professional network of a practitioner.

4. Discussion

The Syseo project tackles four main research domains: data storage, semantic annotation and retrieval, human computer interaction and the size of neoplasias. This section presents some of the main works related to these domains.

4.1. Data storage

The wide use of this standard in the medical domain has led to the development of some DICOM management systems: the picture archiving and communication system (PACS) [5], the most widely used DICOM management system, using mostly relational databases to store DICOM files; eDiaMoND [6], a grid-enabled database of mammogram images and the ORDICOM data type in Oracle 11G [7] enabling to store DICOM file as an object in a column of a database table. Unfortunately, such systems are highly expensive, IT experts-dependent, weak expressiveness or/and not scalable. Particularly, in current systems the crash of a server may prevent doctors from getting the required image if it is not stored on a separate portable disk.

Due to the characteristics of medical data applications such as the heterogeneity, the extremely huge/ever-increasing size, and the expensive storage, it would be beneficial to exploit the power of cloud-based systems, like MapReduce [8], or its open source version Hadoop (http://hadoop.apache.org/), Amazon SimpleDB, Amazon DynamoDB, Amazon RDS (aws.amazon.com), SQL Azure (www.windowsazure.com/services/sql-database/), Pig [9], Hive [10], SCOPE [11] or Jaql [12], to handle such challenges. This is because these systems provide promising solutions of cost-effectiveness, disaster recoverability, elasticity, manageability, and availability. Nevertheless, none of these systems consider the complexity of the DICOM format.

4.2. Semantic annotation and retrieval

The use of description logics reasoning to ground a semantic image retrieval process is not a new idea. We can find two classical approaches [13–16] which correspond to reasoning R1, which is the classical individuals retrieval, and the composition of R2 followed by R1, which amounts to finding images associated to concepts that have the same properties as the query (and maybe others). Other approaches are based on non-standard reasonings (abduction and contraction) [17,18], which imply, however, to use a less expressive language than in our approach. These reasonings generalise the previous ones by enabling a finer ranking of answers. Our work is situated between both approaches: based on standard reasonings with a high expressiveness language, we handle a fine ranking of answers by allowing the user to interact with the query interface.

4.3. Computer vision

Developing a computer-aided neoplasia's size measurement software is part of the field of computer vision, whose major topic is studying how world-size measurements may be inferred from images.

However, most monocular measurement systems such as structure-from-motion provide relative measurements only, unless at least one physical measurement, for instance a world's length or the distance between two camera positions, can be provided [19]. This is not easily possible in colonoscopy: these are no physical length gauge visible nor can one track the flexible colonoscope's tip position. In other words, though those techniques may give an estimate of a neoplasia's shape, they will not recover its absolute size. In terms of practicalities, colonoscopic images also raise extremely specific issues caused in particular by a lack of discriminative visual landmarks and moving specularities (due to wet tissues).

4.4. Human computer interaction

Ongoing research on cloud-based UIs are data-centric [20,21]. We promote an enlarged folder metaphor to integrate the social worth of data. Cloud computing has already been proven in terms of applications and services for health care. Many works proposed models or frameworks based on cloud computing for improving health care services, for instance a framework for colorectal cancer imaging analysis [22]. Other examples of cloud based systems are proposed to automate the process of collecting patients' data, to offer a ubiquitous access of patient health information or to enhance mobile health application for societal services [23].

5. Conclusion

This article presented the Syseo projects and its contributions:

- a hybrid database for the management of highly heterogeneous and voluminous medical data to provide ease of use, extensibility, high performance and ad-hoc queries over DICOM and to get benefit of the elasticity, billing by use and scalability of the cloud;
- a semantic image retrieval approach grounded on a polyp ontology expressed in the OWL language and three composable reasonings;
- a cost-neutral methodology for measuring the size of neoplasias from regular optical images, which does not require special engineering of the colonoscope;
- a service-oriented user interface metaphor taking into account medical aspects as well as user interaction aspects and relying on the concept of socially augmented entity to consider the social dimension of activities and on a formal definition, accompanied by a conceptual representation, applied to gastroenterology.

The Syseo project opens research perspective in the four domains to be considered: data storage, semantic annotation and retrieval, computer vision and human computer interaction.

The next objective, with respect to data storage, is to achieve a high level of QoS that allows querying large amounts of data *via* different types of computing devices. The security of medical data over the cloud could be an interesting future work. Additionally, some optimization (e.g. materialized views, cache manager) should be rethought for our particular structure.

To be effective, a semantic image retrieval process needs to tightly couple ontology modeling, image annotation and retrieval reasoning. This is what we propose here: new polyp ontology, an intuitive annotation interface built from the ontology and three composable reasonings to propose a flexible retrieval. As images are stored in the cloud, an interesting perspective will be to benefit also from the computation capacities of the cloud by moving our reasoning computation there [24,25]. Another perspective of this work is to improve performances of the retrieval reasoning by using an ontological query answering approach, which translates the query and the ontology in a classical relational database context so as to benefit from the perfomances of the existing optimized database management systems [26,27].

Regarding size measurement, our system's main limitation lies in R1, which makes the assumption that the neoplasia is mostly parallel to the colonoscope's distal end plane. This assumption is obviously violated if the neoplasia's slant is too strong. In practice, the gastroenterologists are informed that they must keep the colonoscope in the best possible orientation with respect to the neoplasia being measured, though raising this constraint would make our system more flexible. Our system may also be further improved by decoupling optics and motion blur.

Early feedback shows that the Pearl metaphor constitutes an interesting means to address the sharing of medical data, traceability, capitalization of endoscopic images and thus the improvement health care quality. As a perspective, we planned to develop and to evaluate a fully running prototype as well as investigating the adaptation of the user interface for different contexts of use (e.g. operating room *vs.* medical office with various interaction devices).

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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