# Enhancing Shared Medical Image Functionalities with Image Knowledge Digest and Watermarking

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***Abstract*—This paper deals with remote digital handling and sharing of medical images with their associated knowledge. To improve medical knowledge sharing, as for example in e-learning or remote diagnosis aid applications, we propose to render the image more usable by embedding a Knowledge Digest (KD) in images with watermarking. The proposed KD synthesizes respectively symbolic descriptions of the image, of the findings semiology and similarity rules that contribute to balance the importance of the previous descriptors. Such a digest aims at being used for retrieving similar images with either the same findings or differential diagnoses. Instead of modifying the image file format by adding some extra header information, we use watermarking to embed the KD at the pixel gray level of the image. Watermarking allows also verifying data integrity by inserting in the image a digital signature (DS) computed on both image and KD. The interest of these new image functionalities is illustrated considering users' database update within an e-learning application demonstrator of endoscopic semiology.**

## I. Introduction

MEDICAL image sharing participates to a wide variety of applications ranging from tele-diagnosis to tele-surgery, and promotes also applications like remote diagnosis aid and e-learning [1]. These two last applications are being possible through the ability of comparing images to already treated examinations. Beyond image comparison, similarity research between examinations implies a medical knowledge representation.

In previous works [2] [3], inspired by medical practice, we have defined a bi-leveled – disease and lesion – description language of diagnostic information in endoscopy in order to unify the representation of pathologies and of cases. Upon this analysis of the diagnostic reasoning process, all the elements were joined to a system of decision aid which suggests consistent diagnostic hypothesis and relevant cases according to the problematic case description. This system leans on two bases, one defines the endoscopic knowledge and the second corresponds to a case iconography. To identify potential cases within the same class than the problematic case, the similar case retrieval consists in a classification process upon the endoscopic knowledge. Potential cases are then sorted according to their similarity with the problematic case. Such a system is at the midpoint of the Pattern Recognition and Case Base Reasoning paradigms.

Now, it is the matter of promoting the knowledge base, in particular the finding level which represents semiology in the case of an e-learning application demonstrator project in order to share and teach this endoscopic semiology. The basic principle of our approach is to share with a medical image a knowledge digest (KD) that gives a medical synthetic description and interpretation of the image content. Such a digest will constitute the distributed knowledge and is thereafter exploited: (i) to update user's case and knowledge bases and, (ii) to provide the means allowing similar images retrieval with either the same findings or differential diagnoses.

To share with medical images some concomitant data, one approach consists in adding, when allowed by the image file format, some extra header information. In our scheme, we have opted for watermarking [5]. Watermarking is the insertion of a message in a host document which in our case corresponds to an image. Embedded at the pixel gray level of the image, it means independently of the image file format, it is usually required that the watermark information remains hidden to any unauthorized user (as for data encryption, a secret key is needed to access the watermark content), non-interfering with the use of the watermarked document, that is in our case not modifying image interpretation. Between the different approaches proposed for watermarking medical images, we have retained reversible watermarking. The reversibility property allows the removal of the watermark from the image retrieving exactly the original image. In this work, we extend to JPEG compressed image a reversible watermarking method we have proposed for raw image [6].

Suggested KD and watermarking are jointly exploited at the database level of an e-learning demonstrator of endoscopic semiology. Watermarking makes the image more usable by inserting KD in the image and provides also data integrity control by embedding a digital signature computed on both image and KD.

The rest of this article is organized as follow. In section 2, medical knowledge representations and the proposed KD definition are discussed. In section 3, we remember the reversible watermarking scheme we have developed, and

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present its adaptation to JPEG compressed images. In section 4, the KD watermark constitution is presented as well as the architecture of the e-learning demonstrator of endoscopic semiology. Some concluding remarks are given in section 5.

## II. Medical Image Knowledge

In order to help the endoscopist faced with a complex case, previous work [3] has been done in developing an "intelligent" endoscopic atlas. Such an atlas proposes consistent diagnosis hypothesis and relevant cases according to the endoscopist description of the case. At the same time this development has imposed to analyze the cognitive processes that underlay the medical decision making. Before, presenting the Knowledge Digest structure we remember the knowledge representation it belongs too.

### A. *Endoscopic Information Structuration*

The mechanisms which allow going from observation to endoscopical findings and from endoscopical findings to endoscopical diagnostic refer to the various endoscopist knowledge acquired by training and experience: anatomic knowledge of the normal and surgically modified digestive cavity, knowledge of elementary descriptors of endoscopical findings and knowledge of the combination of endoscopical findings and medical context.

#### 1) *Information Structuration*

Drawn from the physician reasoning and from the Minimal Standard Terminology of the European Society of Gastro-Enterology (ESGE) [4], a bi-leveled description mode of the endoscopic imaging and of the gastro-enterology pathologies is illustrated by the concept of **Scenes** with **Objects** whence three types of Scenes with Objects.

- Physical Scene: the file of an image or of an image sequence is considered to be a Physical Scene. It visualizes an interesting part of the endoscopic exam, showing anomalies, that is the Objects.
- Logical Scene: a medical interpretation of endoscopic imagery, i.e. an endoscopical diagnosis, which associates a peculiar patient context, one or several endoscopic Logical Finding(s) or Object(s) and their eventual spatial relations.
- Conceptual Scene: as abstraction of Logical Scene, the extended definitions of the upper digestive tract pathologies. Patient context, reasons for the endoscopy, one or several Conceptual Objects with their eventual spatial relations, and the complementary procedures to be advised, constitute the medical knowledge of these Scenes.

In these three kinds of scene, lesions or any element of interest, i.e. the "endoscopic findings", constitute the objects that can be depicted through an exhaustive description mode. To each descriptor or feature is associated a set of choices, representative of all possibilities and judiciously defined by the expert.

#### 2) *Knowledge and Case Bases*

Based on the knowledge of medical experts and the terms listed in the Minimal Standard Terminology (MST) [4], this approach leads to an a priori description of 150 Conceptual Scenes (diseases) and 100 Conceptual Objects (endoscopic findings).

The expert squeezes out his knowledge, using Linguistic Valuations (LV) instilling uncertainty or vagueness. Each feature can be judged as without interest, impossible or of interest; in this last case, each feature item must be evaluated as *never*, *exceptional*, *rare*, *frequent* and *always*. A sixth level is also defined (*doubtful*) when the choice between never and exceptional cannot be stated: this level expresses the knowledge limits of the expert.

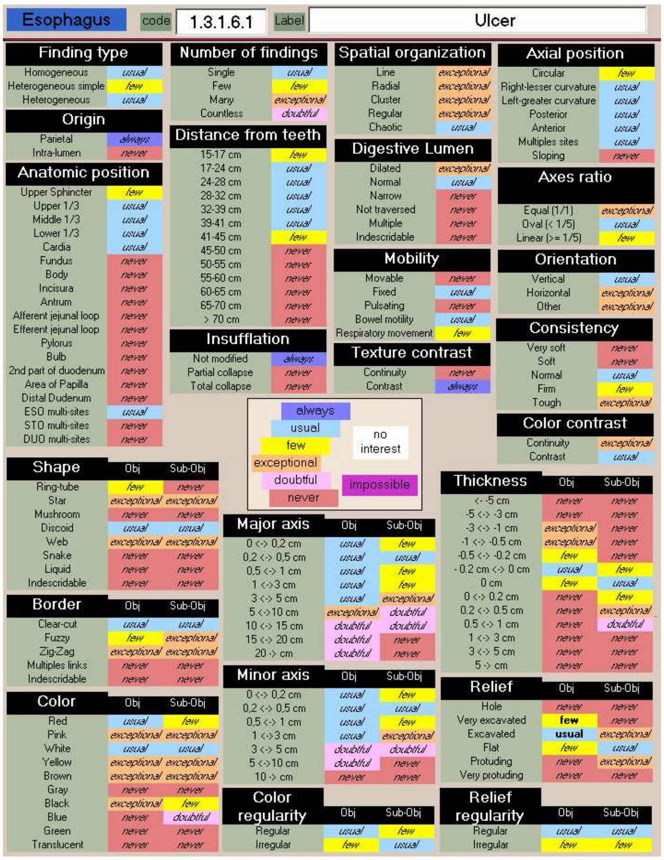


Fig. 1. Example of a Conceptual Object.

An object, identified with a code and a label (cf. figure 1), is systematically described through 33 features as shown in figure 1. To one feature corresponds several items which will be assigned a LV value. The actual number of considered items is 206.

A scene is depicted by a patient profile (the sex and age prevalence features as well as a predefined whole of clinical contexts), by the objects (one of them must be "always") and by eventual spatial relations between objects.

The case base is constituted of indexed images; each of them represents an endoscopic diagnosis with one or more findings. Most of them have been extracted from the Atlas of Digestive Endoscopy - Normed Verlag Editions

(Homburg) - with their authorization.

*3) Reasoning with Knowledge and Cases*

For a new situation, the similar case retrieval leans on the knowledge and case bases. Based on the knowledge base, the system looks for the potential finding and disease classes of the observed case. The retrieval is completed searching into these classes the more similar case according to similarity rules.

The object classification task uses adaptation rules which traduce relationships that exist between the different items. The classification process adapts the knowledge base accordingly to the absence or presence of a feature. For example, feature “type” set as "homogenous" implies that all sub-objects will have their features set as "*impossible*". Similarity rules correspond to cross tables between the items of one feature. There are 33 cross tables. The comparison between two items of a same feature is judged as *incompatible*, *no similar*, *slightly similar*, *fairly similar* or *identical*.

Such an endoscopic system with evolved functionality is in keeping with the Pattern Recognition and Case Base Reasoning paradigms [7].

### B. A Knowledge Digest (KD)

The descriptors of endoscopic anomalies and their content cannot be retrieved in extension in MST. The features we use refer to a lower description level.

In this context, the KD we propose is associated to an image considering that it must be sufficient to retrieve similar images with either the same findings or differential diagnoses. For that, such a digest synthesizes respectively: the symbolic descriptions of the image, of the findings semiology just as the adaptation and similarity rules.

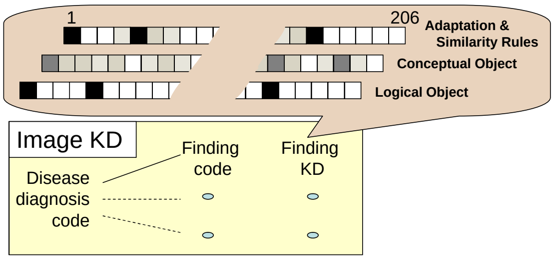


Fig. 2. Knowledge Digest structure.

As described section II.A.2, any object is identified with a code. The KD structure is constituted of (cf. figure 2): the diagnosis code, each identified finding code and their related finding KD.

The finding KD is represented by three vectors of 206 components each: the finding description vector, the finding semiology vector and the adaptation and similarity rules vector. The finding description vector represents the Logical Object (cf. §II.A.1) in the image. Each of its components corresponds to one item. Items which describe the finding in the image are set to 1 and the other ones to 0. The finding semiology vector traduces the knowledge we have on the finding. Each of its components is associated to one item, and takes its value between 0 and 5 representing the LV valuation from *"never"* to "*always*" (cf. II.A.2). The third vector corresponds to the adaptation and similarity rules described in section II.A.3. To each value, from *incompatible* to *identical*, is associated a numerical value 0, 2, 3, 4 or 5. According to the need of adapting rules or not, *Impossible* and *missing* correspond respectively to 0 and 1.

The Knowledge Digest with its synthetic representation of endoscopic information is language independent contrarily to the glossary which allows its interpretation. Nevertheless, we proposed to share such a KD with its associated image.

## III. Enhancing Image Functionalities with Watermarking

To share with images their associated KD watermarking has been retained keeping in mind that these data are intimately associated. It integrates protection data and/or metadata in an image by modifying the pixel gray level of this image. In the context of medical imaging, to absolutely ensure that the watermark will not interfere with the image interpretation, we use reversible watermarking. The scheme we propose was originally devoted to raw medical image data. Based on a generic strategy of watermarking reversibility, we propose an adapted version for JPEG compressed image.

### A. A reversible watermarking scheme

The method we propose derives from the message to be embedded, a watermark signal that is added to the image *I*. It works on signal with samples taking integer values.

Generally, the additive aspect and the limited image depth ($2^p$-1 possible gray levels for an image a *p* bits depth) require taking care of under-flow and over-flow [8]. For example, for an image of 8 bit depth, adding one gray level on a pixel of gray value equal to 255 will be greater than the maximum authorized that is 255, leading to an over flow.

To identify blocks that, if modify, will introduce an under-flow or overflow our approach is based on a pixel block classification. Hence, we consider watermarkable and non-watermarkable blocks, non-watermarkable blocks will not be modified. To retrieve the watermarked blocks in the watermarked image $I_w$ and consequently the embedded message, this classification is built on a signal estimation invariant to the insertion process.

The algorithm we summarize here is completely described in [6]. At first, the image *I* is splitted in 2x2 pixels non-overlapping blocks $\{B_k\}$. A block $B_j$ of 2x2 pixels ($B_j = \{x_{j,00}, x_{j,01}, x_{j,10}, x_{j,11}\}$) will be watermark by adding or subtracting a known watermark pattern *W*. In this experiment, *W* is defined by:

$$W = \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \qquad (1)$$

In a second time, each block is estimated. A block $B_j$ is estimated by $\hat{B}_j = \{\hat{x}_{j,00}, ..., \hat{x}_{j,11}\}$ through a linear combination:

$$\hat{B}_j = \begin{bmatrix} \hat{x}_{j,00} & \hat{x}_{j,01} \\ \hat{x}_{j,10} & \hat{x}_{j,11} \end{bmatrix}$$

$$\hat{B}_j = \frac{1}{4}\begin{bmatrix} x_{j,01} + 2x_{j,00} + x_{j,10} & x_{j,00} + 2x_{j,01} + x_{j,11} \\ x_{j,00} + 2x_{j,10} + x_{j,11} & x_{j,01} + 2x_3 + x_{j,10} \end{bmatrix} \qquad (2)$$

Once $W$ added or subtracted to $B_j$, $\hat{B}_j$ computed on the watermarked block $B_j^w$ keeps the same.

In the classification process, $B_j$ is characterized by two single measures computed over $\hat{B}_j$. One $\hat{B}_j^{\min}$ is devoted to avoid under-flows and the second $\hat{B}_j^{\max}$ to avoid over-flows. They are defined by:

$$\hat{B}_j^{\min} = \min_{k,l}\left(\lfloor \hat{x}_{j,kl}/Q \rfloor, \hat{x}_{j,kl} \in \hat{B}_j\right),\ k,l=0,1 \qquad (3)$$

$$\hat{B}_j^{\max} = \max_{k,l}\left(\lfloor \hat{x}_{j,kl}/Q \rfloor, \hat{x}_{j,kl} \in \hat{B}_j\right),\ k,l=0,1$$

where $Q$, is a quantization step and $\lfloor\ \rfloor$ the integer rounding function. Q must be known from both the embbedder and the watermark extraction. We can then characterize blocks that can be at the origin of an over or under-flow, over the whole image, by identifying within the estimated image two thresholds:

$$T_{\min} = \max_k\left(\hat{B}_k^{\min}\right),\ \text{k=1,…,N} \qquad (4)$$

$$T_{\max} = \min_k\left(\hat{B}_k^{\max}\right),\ \text{k=1,…,N}$$

Watermarkable blocks are those with the following characteristics: $T_{\min} < \hat{B}_j^{\min}$ and $T_{\max} > \hat{B}_j^{\max}$.

In the case these thresholds change after the insertion, the message will be embedded in two steps. In a first time the embedder considers the thresholds that the watermark reader will identify and inserts in the corresponding blocks a part of the message with the original values $T_{min}$ et $T_{max}$. In a second time, the rest of the message is embedded by modifying the last watermarkable blocks.

A binary message *msg* is inserted in watermarkable blocks according to the following procedure:

1) watermarkable blocks are ordered secretly. This step depends on a user secret key.
2) For one block $B_k$, one pixel $x_{k,ij}$ is selected and compared to its estimation $\hat{x}_{k,ij}$. If it satisfies $\left|x_{k,ij} - \hat{x}_{k,ij}\right| < 1$ then $B_k$ is able to carry one bit $b$ and is altered in the following manner :

   If *msg*(*j*)=1 then $B_k^w = B_k + W$

   If *msg*(*j*)=0 then $B_k^w = B_k - W$

   On the contrary, if $\left|x_{k,ij} - \hat{x}_{k,ij}\right| \geq 1$ then the distance between $x_{k,ij}$ and $\hat{x}_{k,ij}$ is increased by adding or subtracting $W$.

At the detection step, the watermark decoder acts in the same way. Once the classification processed, watermarkable bocks are retrieved, re-ordered, interpreted and restored by adding or subtracting the pattern $W$. Based on this approach, message and exact image recovery are possible, only if the watermarked image has not been modified.

### B. *Extension to JPEG compressed images*

JPEG (Joint Photographic Experts Group) is a popular and well know standard for image compression which allows two compression modes (www.jpeg.org): lossless and lossy. The first one, only reduces the image file size through an entropic encoding. On the contrary, the lossy mode, we consider thereafter, authorizes some information loss accordingly to a quality factor $\delta$. The smaller is $\delta$, the lower the image quality is preserved and the higher is the compression file size ratio.

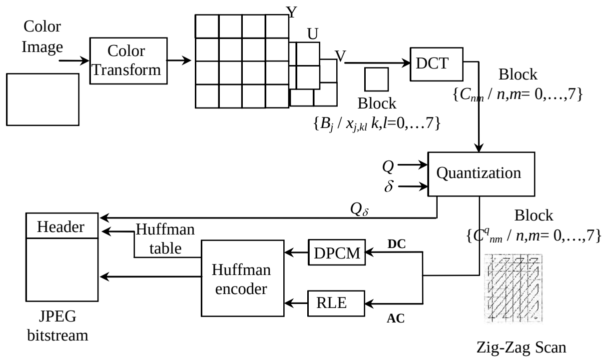


Fig. 3. Overview of the JPEG compression algorithm.

The JPEG algorithm is described in figure 3. It starts by an image color transformation to the YUV space. For each block of four pixels, you have four samples of luminance information (Y), and one each of the two chrominance components (U and V). Each color component is treated independently. The process continues by splitting the image or a color component in 8x8 pixels blocks. A Discrete Cosine Transform (DCT), is applied to each block, leading to blocks of 8x8 transformed and uncorrelated coefficients $C_{nm}$, with $n$=0,…,7 and $m$=0,…,7:

$$C_{nm} = \sum_{i=0}^{7}\sum_{j=0}^{7} x_{ij}\phi(i,\ j)\alpha_i\alpha_j$$

With:

$$\phi(i,\ j) = \cos\left(\frac{\pi(2i+1)j}{16}\right)\cos\left(\frac{\pi(2j+1)i}{16}\right)$$

$$\alpha_i = \sqrt{2/16},\ \alpha_i = 1/\sqrt{16}$$

One coefficient $C_{nm}$ is associated to a spatial frequency ($n$,$m$). $C_{00}$ also named the DC coefficient is proportional to the mean gray level value of the block. The rest of the coefficients (AC coefficients) take their value in the range [-1024; 1023]. This has its importance because it provides a limited depth to the signal.

The information loss is achieved by applying a uniform quantization to each coefficient. The quantization step varies from one coefficient to another and is derived from a standard quantization table $Q$ modulated by the quality factor $\delta$. The resulting quantization table $Q_\delta$ is stored into the jpeg file header. Once the quantization process done, entropic encoding is applied to quantized DCT coefficients.

With JPEG the previous reversible watermarking method can not be exploited in the spatial domain. The watermark is fragile and will be altered after the information loss in the frequency domain. Consequently, we embed the message in the DCT quantized coefficients, it means the integer values:

$$C^q_{nm} = \lfloor C_{nm}/Q_\delta(n,m) \rfloor$$

Because the quantization step depends on the DCT spatial frequency *(n,m)*, the adopted strategy consists in embedding parts of the message independently in several coefficient planes applying our reversible method. A coefficient plane $P_{nm}$ regroups all the image coefficients of same spatial frequency *(n,m)*, with coefficient values varying in the range: $[\![ \lfloor -1024/Q_\delta(n,m) \rfloor ; \lfloor 1023/Q_\delta(n,m) \rfloor ]\!]$. Consequently, our watermarking algorithm keeps the same for one coefficient plane, only the thresholds $T_{min}$ and $T_{max}$ that control lower and over-flows have to be refined. Depending on the message length, the number of watermarked coefficient planes may vary to reach the requirement in terms of capacity. At the detection stage each part of the message has to be extracted from the different watermarked planes. Notes that with such an approach, each time the image is recompressed, the watermark signal should be recomputed.

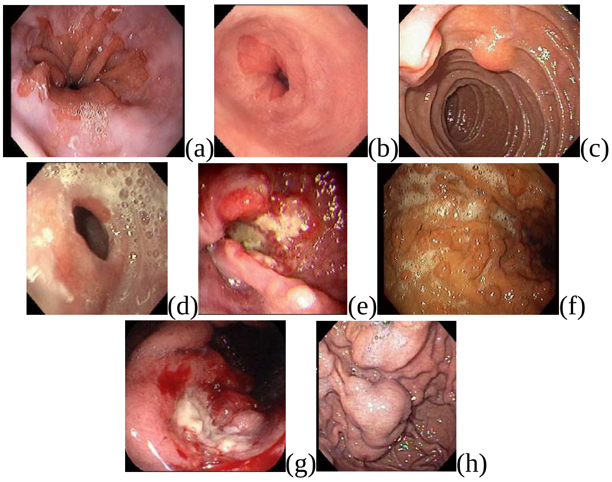


Fig. 4. Illustratives examples: (a) Barrett esophagus (b) Esophagitis, (c) Nodules, (d) Stenosis, (e) Tumor, (f) Polyps, (g) Ulcer, (h) Varices.

## IV. Endoscopic Semiology E-learning Application

The proposed KD and watermarking abilities have been jointly experimented at the database level of an e-learning demonstrator of endoscopic semiology.

### *A. Watermarking endoscopic image knowledge*

In this experiment, we have considered a data base of endoscopic images that give illustrative examples of 8 distinct diseases: Barrett esophagus, esophagitis, nodules, stenosis, tumor, polyps, ulcer and varices.

The KD associated with a single image shall in fact be converted to a binary string, as smallest as possible, before its insertion. As shown in figure 5, the message to be watermarked contains: the total message length, the diagnosis code, the number of identified findings and for each the associated finding code composed of the finding KD size followed by the built finding KD. In order to minimize the size of the whole message to be embedded, the three finding KD vectors are composed before being binarized.

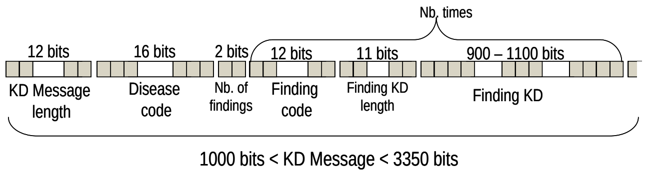


Fig. 5. KD message organization

In general, images visualize one or two lesions, exceptionally three, whence the KD message size stands in average around 1000-2000 bits and, at a maximum of 3350 bits.

In our experiment, the insertion process has only been applied to the Y component of JPEG compressed images, considering a test set of 1500 images. As described section III.B, our algorithm chooses a set of coefficient planes $\{P_{nm}\}$ for embedding. The capacity, it means the number of bit that can be embedded within an image, depends on the number of coefficient planes retained and also on the image size and content. Over the whole image test set, the smallest, average and maximum capacities, expressed in bits of message per image pixel (bpp) considering the set of coefficient planes $\xi=\{P_{nm} \,/\, n=1,..,5,\ m=1,\ldots,5\}$ are respectively: 0.0151 bpp, 0.0223 bpp and 0.0265 bpp. For an image of 368x368 pixels, the smallest message we may expect to embed is around 2000 bits. Nevertheless, depending on the image, our watermarking algorithm can adaptively select the coefficient planes to be used for a given KD length.

The reversibility of our scheme guarantees that once the watermark removed, image alteration is only due to compression information loss. However, keeping the watermark in the image implies a distortion due to the watermark that can be quantitatively evaluated through the Pic Signal to Noise Ratio (PSNR) between the original JPEG image and its watermarked version. Considering the same experiment as previously we have found respectively the smallest, average and maximum distortion to be: 36.4825 dB, 38.8471 dB and 39.7178dB. Even if further experiments are needed, we expect that most of the time the watermark can be kept within the image.

### *B. System architecture*

Our demonstrator will be implemented using Matlab® (MathWorks) and an Apache Web Server. As depicted in figure 6, its architecture is based on a web server that gives access to an image database through a website publicly available. A user just has to use his web browser with the appropriate URL. With Matlab installed on its computer, he will be able to benefit from the distributed functionalities.

At the server side, before images are made available on the website, each image is JPEG compressed at a prefixed quality factor and watermarked, in the way illustrated in figure 7. A Digital Signature (DS) is computed over both the image KD, retrieved from the database, and the un-watermarked compressed image. Then KD and DS are embedded according to a secret watermarking key. Digitally signing the KD and the image will certify to the user that the information is reliable, giving proofs of data origins and integrity. In this experiment we use the DSA signature [9] which provides a 160 bit long DS. If the image or the KD are modified, the re-computed digital signature will be different than the embedded one. Hence, the user will be informed that data have been modified and the system will not exploits them.

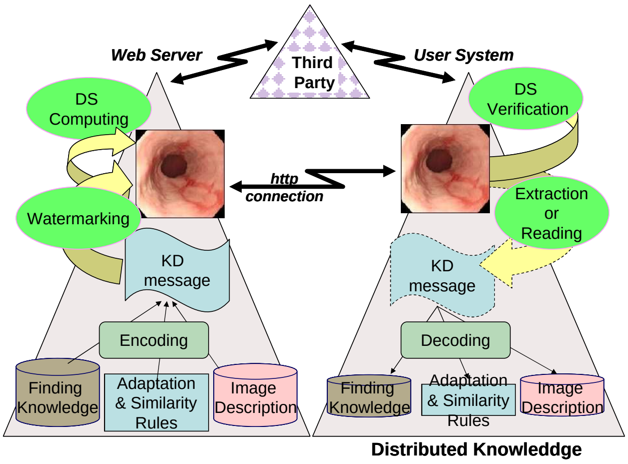


Fig. 6. System architecture.

Hence, when a user connects on the web server, all information as well as watermarked images are publicly available. If he possesses the watermark extractor with the appropriate watermarking secret key his system will extract the information. The secret key knowledge needs the user to be registered on the server side. In the same vein, a third party will be requested to send the cryptographic keys needed for the integrity control task. This will help also each party to be authenticated as such a key is user dependent. Once the data integrity checked [10], the system updates the user data bases, uploading the new image and the Knowledge Digest. The watermark extractor along with empty databases, KD management functions and the user's language glossary will constitute the plug-in available to registered user.

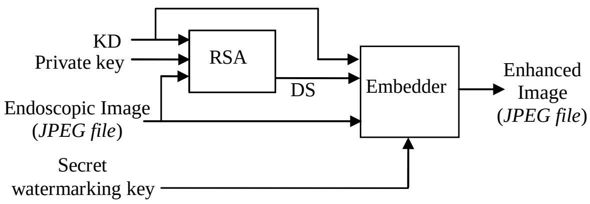


Fig. 7. Watermarking system.

## V. Conclusion

In this article we have proposed a new way to share and to enhance medical images functionalities. While watermarking allows sharing information independently of the image format, the proposed knowledge digest gives a synthetic description of the image content which can be used for retrieving similar images with either the same findings or differential diagnoses. KD combined with watermarking appears as a flexible solution to update distant user case and knowledge databases, similarity rules.

In this work we have also extended a reversible scheme in application to JPEG compressed images. It provides high capacity and may enable other useful application in the same vein than the presented e-learning demonstrator. In future works, we will still optimize the watermarking capacities of the endoscopic images, in order to integrate more knowledge, i.e. disease semiology level. Hence, Physical Scene, Logical Scene, Conceptual Scene and Reasoning Rules will be combined in an image-case, in the spirit of the Case Based Reasoning (CBR) for which a case represents all information and processing useful to its resolution.

The endoscopic e-learning could prepare resident to practice on real cases and thwart the inherent threefold weaknesses of the endoscopy teaching: "the unhappy patient, the unhappy student and the unhappy instructor".

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