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CONTENT-BASED RETRIEVAL SYSTEM AS A TELEMEDICAL TOOL

The problem of medical teleconsultations with intelligent computer system rather than with a human expert is analyzed. System for content-based retrieval of images is described and presented as a use case of telemedical tool. Selected features, crucial for retrieval quality, are introduced including: synthesis of parametric images, regions of interest detection and extraction, definition of content-based features, generation of descriptors, query algebra, system architecture and performance. Additionally, electronic business pattern is proposed to generalize teleconsultation services like content-based retrieval systems

1. INTRODUCTION

The provider-patient relationship predates by centuries the explosion of modern technology, remains special by its very nature, and deserves any improvement and preservation that technology has to offer [5]. In telemedicine the fundamental requirement become the same: introducing technological support in healthcare the quality of service should be at least the same as without such a support. Intelligent support of physicians with computer-assisted diagnosis (CAD) tools is a one of the most active area of research and development. One of the CAD techniques is retrieving images from medical databases either locally or over computer networks. However, to support differential analysis it is required to retrieve data by visual features (passive telemedicine service for teleconsultations). Medical professional analyzing a difficult patient case may query the Intelligent System (service provided by another business site) to retrieve, truly diagnosed (verified), similar cases from World-Wide data warehouse. This can be implemented by Content-Based Image Query CBIQ system.

Parametric imaging becomes more and more popular. This includes DSC-MRI [4], ASL MRI [12], dynamic PET/SPECT [3], dynamic active thermography [7], etc. Parametric images represent values of reconstructed parameters for assumed tissue/activity model. Those parameters can be used as descriptors in similarity analysis. Since interpretation of parametric images is difficult (functional images), then differential diagnosis and content-based retrieval methodology seems very attractive.

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2. METHODS

The objective of the content based image query system (CBIQ) is to efficiently find and retrieve those images from a database that are similar to the query image according to specified rules. Definition of a set of query rules and elements e.g., arguments, properties of arguments, operations, parameters (variables, constants); composes the CBIQ algebra. The query algebra is different from a typical database query system in that it entails a visual features similarity search. It is possible to define two basic forms of queries in CBIQ[11, 8]:

Q 1. K-nearest neighbour query.
Given a query image Iq and a collection C of N target images, find K images It (It $\subset$ C) with the highest similarity s(Iq, It) to the image Iq.

Q 2. Range (threshold query).
Given a query image Iq, a threshold value of similarity T and a collection C of N target images, find all images It (part of C) with the similarity measure s(Iq, It)>T.

Two parameters of these queries, the threshold value of similarity T and the number of most similar images K, are defined by a user before the query processes. It is also possible to sort selected images according to the similarity measure value. There are many variations of the presented queries, some of them are presented in [9].

Implementation of presented queries requires precise description of similarity measures. The problem is how to implement the similarity measurement operation *s(Oq, Ot)* , where: *Oq* is a query object (a region, an image) and *Ot* is a test object (a region, an image). A following procedure can be proposed:

a) Let the object be a part or a whole image represented by the two-dimensional matrix *Ik(x,y);* where *k* - the object index, *(x,y)* - co-ordinates of an element of the object matrix. The object *Ik(x,y)* is a member of objects collection: *C = { Ik(x,y) }, k $\in$ 0..N-1, (N -* number of objects).

b) Let the object be represented by a set of properties (features): *F = { fi(k) }, i $\in$ 0..I-1, (I -* a number of the object features). The possible features depend of the image type.

c) Let the each feature be described by a set of values - descriptors - which can be directly used to represent given object: *D = { dj(i,k) }, j $\in$ 0..J-1, (J -* a number of descriptors). Some examples of descriptors are Fourier coefficients, Wavelet coefficients, statistical parameters (e.g., a mean, an entropy), etc. [10].

d) Let's define a similarity measurement function using distance measure e.g.: d *(Oq, Ot)* -

$$s(Oq, Ot)=h(d\ (Oq, Ot));\qquad\qquad(1)$$

where:　　 h – transformation function: distance->similarity;　$\Re_0^+ \to [0,1]$,　$h(0)=1$, $d_1 \le d_2 \Rightarrow h(d_1) \ge h(d_2); \forall d_1, d_2 \in \Re_0^+$.

We assumed the *h(d)* is given by [2]:

$$h(d) = \exp(\frac{-d}{\sigma}) \ , \qquad\qquad (2)$$

where: σ - distance standard deviation for chosen descriptors.

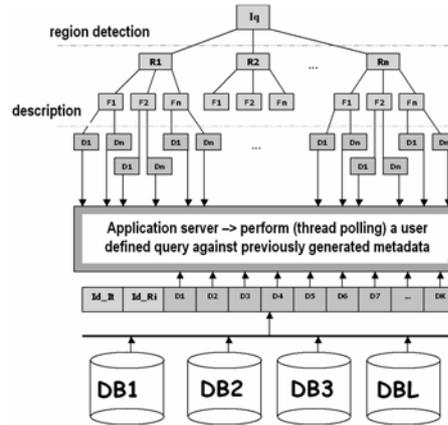In Fig. 1 the overall retrieval process is illustrated.

Fig. 1. Illustration of implemented retrieval process.

A. Image description

Run-length codes (RLC) are generated for a segmented image (manually or using the adaptive thresholding technique). With the one pass scanning of an image a table consisting of N runs is constructed. Each row of the table stores four run attributes: a value of the run V; the first pixel of the run FP (From Pixel); the last pixel of the run TP (To Pixel); and the region label which the run belongs to (RLC={V, FP, TP, ID}). As a result all unique regions are labelled, which produces a set of run-length encoded (RLE) regions. The whole algorithm requires only the previous image raw runs to test for adjacency and a single vector for equivalence analysis. It operates very fast since only iteration and comparison operations are required. With the RLE-regions a set o descriptors is proposed for intensity, regularity and shape features including:

- a set of first order statistical descriptors;
- a Minimum Bounding Rectangle (*MBR*) – *min/max, FP, TP* values of a region runs;
- an area of a region

$$A = \sum_{i=1}^{R}(TP_i - FP_i + 1), \qquad\qquad (3)$$

where R – the total number of region runs. Small regions are merged using intensity and common border similarities;

- a region contour *{B(n,m)}* and a perimeter *P* – number of *(FP, TP)* pixels of vertical and horizontal runs (or No of pixels after application of morphological gradient *Rp=R-E(R,N4)*, *R*–region, *E*-erosion, *N4*–structural element [0 1 0][1 1 1][0 1 0]);
- a compactness:

$$C = \frac{P^2}{A} \; ; \qquad\qquad (4)$$

- a region centroid (a centre of a region gravity) $G(x,y)$ – according to statistical moments:

$x = \frac{M_{1,0}}{M_{0,0}}; y = \frac{M_{0,1}}{M_{0,0}};$ $M_{0,0}$=A and $M_{1,0}, M_{0,1}$ can be calculated as the sum of horizontal

($M_{1,0}$)/vertical ($M_{0,1}$) runs indexes: $M_{1,0} = \sum\limits_{i=FP}^{TP} i$, $M_{0,1} = \sum\limits_{i=FP}^{TP} i$;

- a set of the first order statistical descriptors based on a histogram of the region contour to the centre of gravity distances distribution *{B(n,m)-G(x,y)}*,

$$h_k \left[\sqrt{(x_i - x)^2 + (y_j - y)^2} \right], \; (x_i, y_j) \in B ; \qquad\qquad (5)$$

- a set of the first order statistical descriptors based on horizontal/vertical run-length distributions, histograms: $h_h[(PK_i-PP_i+1)]$, $h_v[(PK_i-PP_i+1)]$;

normalised energy E_{hv} and entropy H_{hv}:

$$E_{hv} = \frac{E_h + E_v}{\mu_h + \mu_v}, \; H_{hv} = \frac{H_h + H_v}{\mu_h + \mu_v} ; \qquad\qquad (6)$$

- spot density descriptor,

$$D_S = \frac{N_S}{A}, \qquad\qquad (7)$$

Ns – No of runs with length = 1.

Additionally a set of functions for region topology analysis like distance, adjacency, overlay, neighbourhood, etc., are defined using RLC description of regions and centres of gravity. Concluding, RLC based descriptors for shape, structure and values construct the full region representation for content based retrieval purposes. Description can be stored as rows in tables (e.g., in a relational database) or as persistent objects (in an object oriented database).

B. Parametric images

Synthesis of parametric images uses dynamically measured data fitted to the model characteristics. In this study we used parametric images for dynamic, active thermography (AT) and dynamic susceptibility contrast (DSC) MRI.

AT parametric images

In the pulsed thermography a target object is excited (fan cooling and optical heating, used in the reported study) during a given time period t_1. As a result of the heating the object

temperature varies in time according to thermal properties of the object. Taking into account a single point of the object its temperature can be represented as

$$S_i^p = \left\{ s_1^p, s_2^p, s_2^p, ..., s_i^p \right\},$$ (8)

where: i – total number of samples measured during cooling, p – index of a measurement point.

Sequence of images was measured to calculate a set of samples for each point in time. Images can be recorded by thermal camera with frequency adjusted to the object properties and heating conditions. In the applied pulsed thermography the optical heating (a set of lamps - 1000W) and fan cooling excitation was usually lasting 30s. Thermal images were captured every 1s during 180 seconds (180 images, 180 samples for a one pixel). The character of sample values distribution is exponential and can be described by the formula

$$\hat{s}_i^p = B_0^p + \sum_{j=1}^{N} B_j^p * \exp\left(-\frac{t_{i-1}}{\tau_j^p} \right); i = 1..c$$ (9)

where: B – amplitudes, $\hat{s}_i^p$ - analytical value of a sample, $\tau_j{}^p$ - time constant for layer j. We explore one and two layers model (two time constants) which proof to be sufficient (A1= B_1^p, A2=1/τ_1^p, A3= B_2^p, A4=1/τ_2^p). The equation describes also a simple RC electrical circuit with the time constant τ^p=R*C. For thermal studies the model and its parameters represent thermal properties of the object (conductivity, heat capacity). Quantitative description for the thermography can base on such parameters. Parametric image reconstruction method is looking for parameters of the equation (1) which minimize fitting errors to the measured set of samples. This is achieved by the application of the χ^2 test, and the fitting algorithm. We used Marquardt method.

DSC MRI parametric images
In the DSC-MRI brain studies, after injection of a bolus of contrast agent (Gd-DTPA), a series of images are measured. This time-sequence data presents local voxel activity of contrast (blood) flow and distribution. It is assumed, that measured MRI signal values are proportional to the contrast concentration. Contrast concentration as a function of time is measured for brain supported arteries. This function can be estimated as the arterial input function (AIF). Assuming ideal conditions this function should be an ideal impulse function, so measuring the output function (impulse response) one can specify properties of the object under study, including mass flow, mass volume, and mean transfer time. Since AIF is not an ideal impulse function (dispersion and delay) and because in DSC-MRI measurements are done from volume of interest (VOI), deconvolution should be used to calculate VOI impulse response [6]

$$C_t(t) = \frac{\rho}{Kh} \int_0^t C_a(\tau) \cdot \left(F \cdot R(t-\tau) \right) d\tau,$$ (10)

where: $C_a(t)$ - contrast concentration in the artery (e.g., Middle Cerebral Artery) – Arterial Input Function AIF,

- $C_t(t)$ - contrast concentration in the tissue,

- $\dfrac{\rho}{Kh}$ - scaling factor (quantitative description) ρ – mean tissue density of a brain, $\rho=1,04 \ g/mol$; Kh – hematocrit ration (large to small arteries) $Kh=(1-Hd)/(1-Hm)$; $Hd=0.45$; $Hm=0.25$,

- $F*R(t)$ – scaled impulse response (residue function) inside VOI, $R(t)$ - represents fractional tissue concentration:

$$R(t) = 1 - H(t) = 1 - \int_0^t h(\tau) \cdot d\tau , \qquad (11)$$

- $h(t)$ - transport function - impulse response (an ideal instantaneous unit bolus injection). Distribution of transit times through the voxel; depends on the vascular structure and flow.

The model is based on tracer kinetics for nondiffusable tracers – contrast material remains intravascular [13].

Scaled impulse response could be calculated using Fourier transforms (FFT) or matrix algebra (with matrix decomposition SVD to eliminate singularities). Since $R(t=0)$ should be equal to 1, then

$$F \cdot R(t=0) = F = CBF \ (Cerebral \ Blood \ Flow). \qquad (12)$$

Cerebral blood volume (proportional to the normalized total amount of tracer) can be calculated as

$$CBV = \int_0^\infty C_t(\tau) \cdot d\tau \ \Big/ \ \frac{\rho}{Kh} \int_0^\infty C_a(\tau) \cdot d\tau . \qquad (13)$$

Based on central volume theorem, mean transit time (average time required for any given particle of tracer to pass through the tissue after an ideal bolus injection) can be estimated as

$$MTT = CBV/CBF. \qquad (14).$$

Three types of quantitative parametric images (CBF, CBV, MTT), synthesized under strictly controlled procedure, offer additional space to construct new descriptors for content based retrieval.

3. RESULTS

The CBIR system was implemented using Java JDK 1.2. It consists of three layers (Fig. 2):

- image content description generator for image databases (a standalone application),
- CBIR client – requested by Java Network Launching Protocol a graphical client used for a query specification,
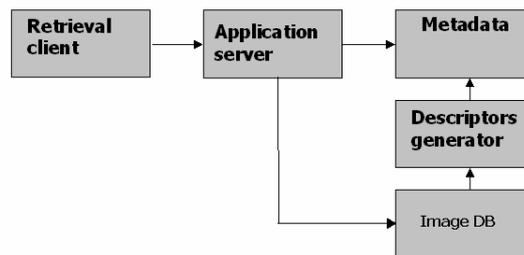- Query engine running on the application server.

Fig. 2. The CBIR system simplified architecture.

As a result of selection the set of images (cases) is generated. The developed system is running by Java Network Launching Protocol through WWW. Results of performance testing are promising: without database indexing and using database of 31 874 image regions with 25 descriptors calculation of similarity measures and sorting took about 3 s (Pentium III 800MHz/128MB RAM). Retrieval effectiveness was also tested using sets of 6000 structural MRI, DSC-MRI and AT images. Calculated Average Retrieval Rate (ARR – MPEG 7) values are 74% (MRI), 71% (DSC-MRI), 73% (AT). The best results were achieved with a set of CT images (ARR>80%) used as a reference. This is caused by high repetitiveness of intensity values (CT numbers) in CT imaging, where intensity is a primary image feature. Similar role plays colour in real world images, so colour-based image retrieval is very popular for this class of images. In MRI and thermography colour is not a property of measured objects (we use colour tables/pseudocolours) so it can not be used for retrieval.

4. DISCUSSION AND CONCLUSION

Intelligent assistant tools are highly required and possible to implement with reasonable quality/retrieval speed parameters. Generalizing the CAD role and taking into account importance of ebPatterns [1] it could be concluded by definition of the ebPattern for presented online CAD system.

Electronic Business Pattern: Customer-to-Online CAD

The C2OCAD business pattern can be designed as a subtype of User-to-Business pattern **(1)** or subtype of User-to-Data pattern **(2)**.

(1) CAD is offered as a subscribed (paid) service. A customer requesting a service defines the query image objects and parameters using a service-provider application.

(2) CAD is offered as a solution that allows users to extract (retrieve, generate, discover) useful information from large image databases.

(1,2) Business and IT drivers:

a) The end-users and customers need to directly interact with business processes and/or data,

b) The business activity has a need to aggregate, organize and present information from various sources within and outside of the organization (*e.g., hospital*),

c) The business process must be reachable in a common, consistent, and simplifier manner through multiply delivery channels.

Context: Users of applications built according to the C2OCAD ebPattern might be internal or external to an organization. In both cases the objective is to transform a query data to useful diagnostic information for a given medical case. In (1), application that implements this pattern facilities direct interaction between users and processes (application server). In (2), pattern implementing application facilities direct interaction between users and data/metadata. This interaction can use user-defined methods, for example offered by data mining technology.

Solution: This pattern typically consists of the following:

Users, who: - may be within the enterprise, in partner organizations, or in any other location across the globe, - will have different preferences and want to access different views of the data and of the results of retrieval, - will typically access the solution using a Web browser or a browser-based Internet appliance.

A network which: - is based on TCP/IP and other Internet technologies,

- can be dedicated LAN connection, - can used encrypted transmission (e.g., Virtual Private Network VPN).

Enterprise systems, which can be: - custom-developed systems - databases.

Other systems, such as: -other Web Services, - other databases.

A set of interactions representing the business functions provided to users, or interactions with data.

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