An Interface System Based on Multimodal Principle for Cardiological Diagnosis Assistance

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Abstract: *A pilot interface system is developed for computer-aided diagnostic and interventional assistance of cardiologists based on clinical trials. The system includes optimized methods for processing and presentation of cardiological knowledge and data. The multimodal principle of the interface is based on know-how tests of a new magnetic microsensor for detection of catheter navigation in images from angiograms and intra-vascular ultrasound and on new investigations of the principle of operation of the electrocardiograph. The user interface includes interactive access to the clinical database and a cognitive approach to disease visualization.*

Key words: *Cardiovascular diagnosis, angiogram and intravascular ultrasound analysis, catheter path reconstruction, magneto-sensitivity.*

INTRODUCTION

ActiveVessel is a new application designed to fuse the information coming from the angiographic, intravascular ultrasound (IVUS), electro-cardiographic (ECG) and magnetic equipments, and is currently developed in close cooperation with acting cardiologists to assist their diagnostic and intervention work [5]. It is a tool for hospitals using IVUS and angiography for on- and off-line evaluation of stenosis, stent implantation and balloon treatments. The integration with the magnetic modality is a novel feature, which is expected by the interventional cardiologists as one of the technical solutions, urgently needed in transcatheter interventional cardiology [3].

Recently, Ascension Technology announced its new medical tracking device for transcatheter cardiovascular intervention - 3D Guidance [12]. The commercially available device is a 1.3 mm sensor integrated into the catheter. Our proposal for the integration of the microsensor for magnetic field into the catheter focuses on the alternative to the mainstream and costly recent medical technology solutions. The microsensor with simplified structure and enhanced sensitivity is a new, smart and low-cost technical device of comparable-to-superior parameters - improved structure, smaller size and higher fidelity [9], [10]. Devices of this kind are still under construction in the leading technological centres.

The paper presents the current state of development of the multimodal interface and the basic new functionalities of ActiveVessel – catheter path reconstruction based on fusion of angiography and IVUS data and extraction of volumetric information; cognitive preferences of the cardiologists, accounted for in the colour-coded distance map in ultrasound images; the proposed technical extension of the system with a new magneto-sensitive micro-device implemented in the catheter and the new technical-diagnostic module of the ECG device. The scientific relevance is the integration of microsensor and cognitively-oriented information technology based on new research. Current system design aims at parallel exploration of ideas and technical solutions that can contribute to the invention of new optimised, low-cost, smart medical devices for wider availability of high quality health care.

CATHETER PATH RECONSTRUCTION FROM ANGIOGRAPHY AND IVUS DATA

X-Ray images are characterized with low signal-to-noise rate. The fusion process begins with local enhancement of the angiographic image. The method consists of establishing a global reference system with its origin in the isocenter of both angiographic image projections of the IVUS catheter. The way of placing the models along the 3D curve corresponding to the IVUS pullback is by orienting the X and Y axes of the IVUS image

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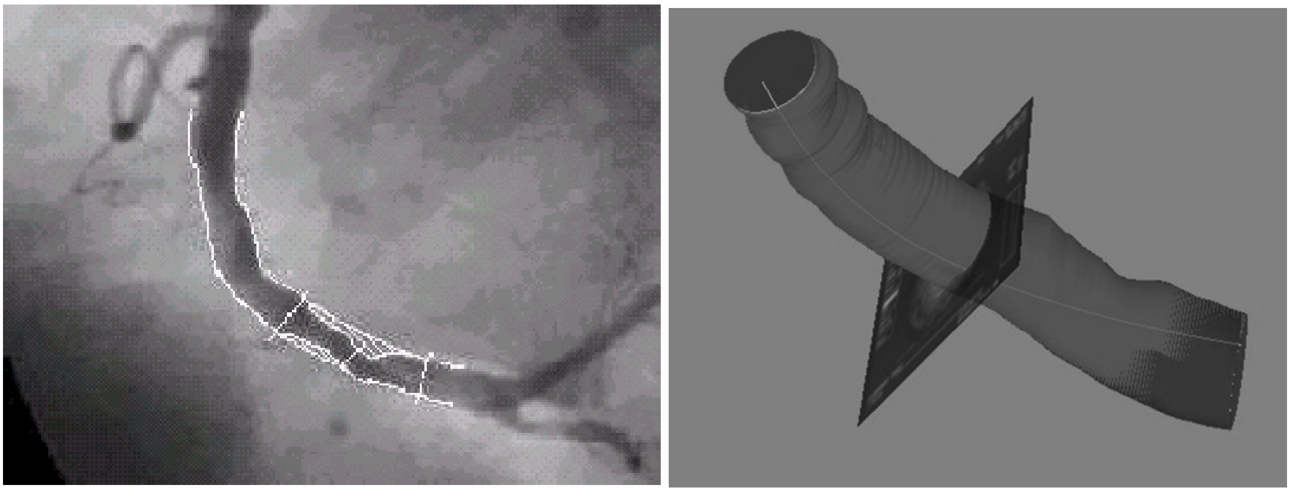
with the normal and bi-normal of the curve, respectively [7], [8].



a) b)

Figure 1. Automatic segmentation of a) 2D vessel borders for evaluation of stenosis; b) 3D vessel reconstruction from angiography and IVUS data

The three-dimensional visualization is performed in "near" real-time and is a distinguishing feature of ActiveVessel (figure 1). It recovers the real 3D path, which the catheter has followed during its pullback inside the blood vessel. The image fusion process leads to exact correspondence between IVUS and angiograms. The exact correspondence is established by measuring the reconstructed path length in 3D. This is one of the main modules of the application, involving direct interaction between the cardiologist and the resulting image modalities at one and the same time.

The used catheter has a diameter of 1 mm in order to be introduced in the coronary vessel. Thus, the catheter trajectory not necessarily corresponds to the centre of the vessel as expected. This fact is very important in order to locate IVUS images in space and recover the shape of the coronary vessel in the right way since in the ultrasound images the mutual position between the catheter head and the vessel borders have to be located and used. An automatic approach for catheter segmentation in angiographies is developed and implemented [1].

The segmentation of the vessel borders is performed using the technique of snakes that deform on the images attracted by the border descriptors. The description of the borders is performed following a statistic-deterministic approach [2]. An example of snake plasticity is the application of a deformable cylinder to a segment and the reconstruction of the stent and the vessel wall from an IVUS images stack, instead of the classical approach of segmenting 3D image volumes slice by slice. The advantage of this approach is mainly in its robustness that stems from the internal energy, which takes into account the coherence between the image planes (figure 2).

Extracting volumetric information is important in order to evaluate the intervention effects. Usually, area and distance calculus in IVUS planes are the only possible ones carried out with IVUS images. Having a B-Spline representation of the vessel and the stent, the distance between them is estimated using a filling algorithm (Y-X, for example) in the images with drawn vessel and stent models. The area of each model is calculated in pixels and the intersectional area (s) is inferred as:

$$s = c^2{}_H * (a_v - a_s) \tag{1}$$

where c_H is the horizontal calibration and a_v and a_s are the vessel and the stent areas, respectively. The area calculus is extrapolated using trapezoids to get the volumetric measurement as follows:

$$V = | s_i - s_{i+1} | * c_v \tag{2}$$

where c_v is the vertical calibration defined by the pullback speed (the distance in millimetres between two images) and s_i and s_{i+1} are the intersectional areas of two consecutive planes.

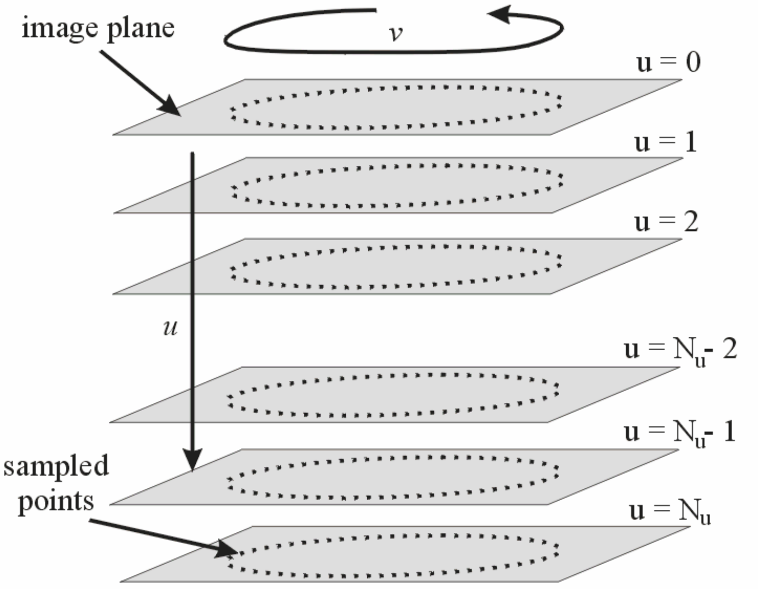


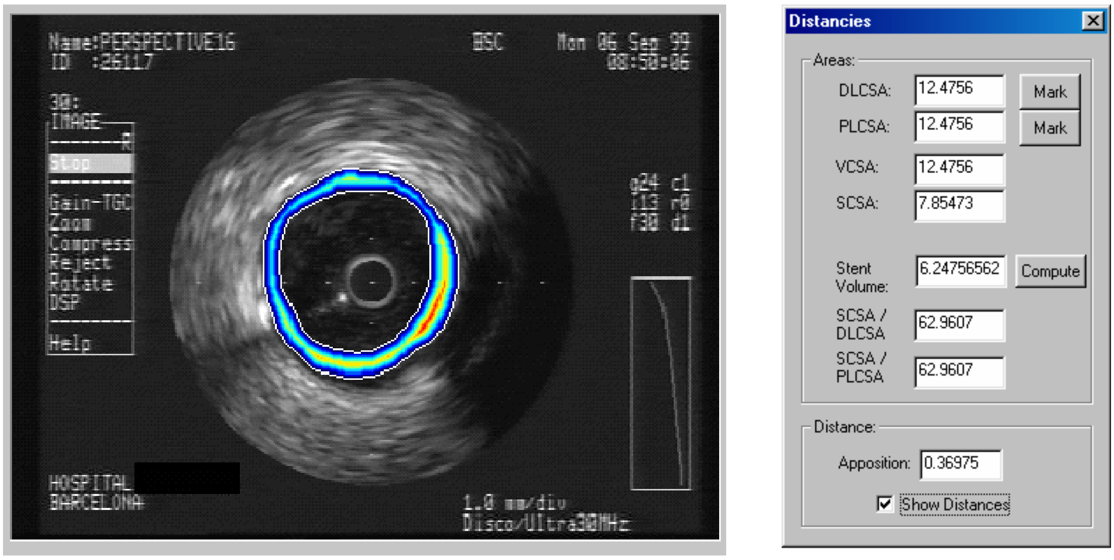
Figure 2. Control points defined to make the knots coincide with image planes

As a result, the cardiologists have a tool to explore the real extension of the coronary disease not in an image or a sequence, but in space, as well as to measure more accurately its effect. Currently, the system is under clinical validation, extracting information from a large series of patients and comparing previous results with the new ones to estimate the importance of volumetric vessel measurements. A natural extension of this work includes creating a virtual reality environment for realistic navigation and interaction with the vessel, simulating vessel interventions and implementing the automatic correction of the vessel rotation and automatic segmentation of the vessel layers.

COLOUR-CODED DISTANCE MAP IN ULTRASOUND IMAGES BASED ON THE COGNITIVE PREFERENCES OF THE CARDIOLOGISTS

The colour-coded distance map is one of the original ways of representation of IVUS data in ActiveVessel. The intensity of the ultrasound images corresponds to the penetration ability of the ultrasound signal interacting with the coronary tissue. The higher the opacity of the tissue the less the penetration of the ultrasound signal hence the brighter the region in the image. This fact was used to find the vessel borders, associating opacity with different colours.

Several measurements are applied in order to estimate the quality of the stent deployment by the IVUS criteria defined in [6], which have three parameters: cross-sectional area (CSA), apposition and symmetry. The ratio of the minimal CSA of the stent to the normal reference vessel CSA (the average CSA proximal and distal to the stent) should be greater than 0.8. The maximum gap between the stent and the vessel wall should not be greater than 0.1mm (apposition). The ratio of the stent minor axis to the stent major axis should be at least 0.7. The parameters are obtained plane-by-plane and are accessible to the cardiologist in terms of numerical data.



Areas:

DLCSA: 12.4756

PLCSA: 12.4756

VCSA: 12.4756

SCSA: 7.85473

Stent Volume: 6.24756562

SCSA / DLCSA: 62.9607

SCSA / PLCSA: 62.9607

Distance:

Apposition: 0.36975

☑ Show Distances

Figure 3. Colour-coded distance map of the mutual position of the stent and the vessel wall

For the apposition case, a colour-coded distance map is offered for more comprehensive interpretation of the stent deployment in the current plane. The colour of each pixel indexes the distance between the two shapes in colour-spectrum terms, where blue is the closest distance and red is the furthest distance. The maximum value (the brightest-red pixels) denotes the biggest gap between the vessel and the stent (figure 3). The colour-map coding has been requested by the cardiologists in order to improve their fast exploration of bad apposition of stents and high accumulation of coronary plaques.

TECHNICAL EXTENSIONS OF THE MULTIMODAL INTERFACE

One of the current development lines of ActiveVessel is the integration with a magneto-sensor for precise 3D positioning of the catheter to simplify the image acquisition protocol. For this purpose, silicon micro-transducers can be applied, functioning on the basis of the Hall effect and the magneto-transistor and magneto-diode effects [9], [10].

Based on these effects, 2D and 3D micro-systems of about 1 mm size are manufactured. They contain, along with the sensor, components of the electronics that process the data. These micro-devices are with enhanced precision of processing information while substantially reducing the parasite noise. To achieve this, the new microsensors are with parallel axis of sensitivity. All this makes them appropriate to implement in medical applications.The device design of the new integrated 3D Hall sensor is shown in figure 4. It uses the first parallel-field Hall element, devised in 1983, which has three n+ contacts. Despite of its simplicity, this micro-transducer has characteristics and performance, which are as good as those of all four-contact, five-contact, six-contact and other parallel-field Hall modifications created until now [9], [10], [11].

In order to function usefully in minimal invasive surgery the magnetic sensor micro-device needs a generator of magnetic field (e.g. located on the image intensifier).

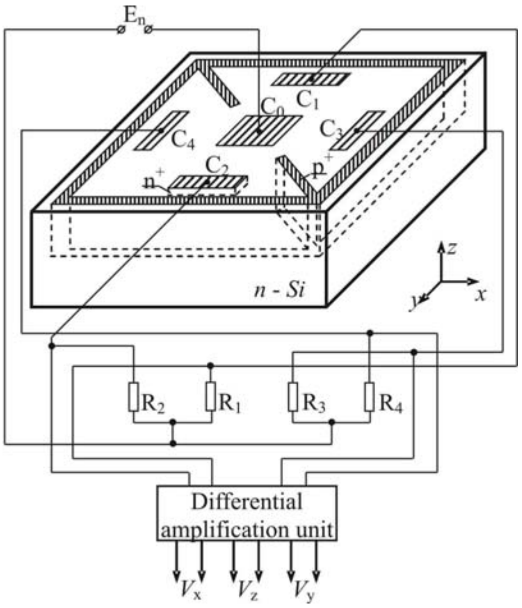


Figure 4. 3D silicon-based magnetometer with simplified structure and enhanced sensitivity suitable for miniaturization

The motion of the catheter with the magnetic sensor inside the vessel initialises the useful information via the magneto-sensitive output signal in the presence of magnetic field.The proposed solution here is a new and original one. It integrates sensor and processing in one and the same chip. The construction is simplified with reduced number of contacts and allows registration of the 3D sensor position with very high precision.

A new technical-diagnostic module to the ECG device

The medical workstation is equipped with a real-time video and an ECG recording module. A video output of the angiographic equipment, containing the same information shown on the laboratory monitors, is used as an input for the system. Once the ECG is recovered and the angiographic images are recorded, the angiographies are selected automatically corresponding to the end of the S curve of the ECG to assure maximum ventricular volume. The same recording procedure is taken for the IVUS data. The overall precision of the visualization module depends on the precision of the ECG signal. To enhance fidelity, a module for technical diagnostics of the ECG device is implemented, based on new tests of its performance [4].

CONCLUSIONS AND FUTURE WORK

ActiveVessel as a medical visualisation tool has been designed especially for cardiology in close cooperation with the medical staff, accounting for the cognitive preferences of the cardiologists. Next steps in the development of ActiveVessel will be interface oriented to make the dialogue with the cardiologist more flexible and with enhanced semantics. ActiveVessel will be integrated with Web-based technologies for remote access to medical and image databases. The contribution of the paper is the presentation of a currently developed system for cardiological assistance designed in collaboration with the actual users of the system – the cardiologists – and the smart solutions accompanying its development.

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