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Intracorporeal Videoprobe (IVP)

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Abstract.
The objective of the work in the EC project IVP is the development and evaluation of two prototypes of video systems:

- a small wired videoprobe with a CMOS image sensor

and

- an autonomous video-capsule with a telemetric link for image data transfer to an external PC-based system.

Introduction

Visualisation of the status of organs health is one major task in medical diagnosis and therapy. Endoscopy and minimal invasive surgery are techniques for this purpose in medical applications. Recent developments in microelectronics allow the fabrication of advanced and highly integrated image sensors and improved solutions for miniaturisation and wireless data transmission.

In endoscopy important aspects are the demand for smaller devices and the wish to integrate high quality, but low cost visualisation techniques [1]. Moreover the problems and cost of sterilisation raised the wish to fabricate disposable endoscope heads.

While the majority of endoscopes uses optical lens systems (rigid endoscopes) or fiber bundles (flexible endoscopes) to transmit the images to a camera, video-endoscopes have the camera directly at the tip. Thus such an endoscope head is a microsystem with image sensor chip, optics and illumination and electrical wiring.

Image data are transmitted via cables, which also provide the power for the system. The wired videoprobe IVP1 is described in the first part of the paper.

Autonomous videoprobes on the other hand, use wireless data transmission and need an internal the power supply. The most prominent development of such an autonomous video-capsule is the M2A system of Given Imaging [2] a battery powered system with a CMOS image sensor. Other developments in this field describe external powering systems [3] or even work with CCDs (Charge Coupled Devices) and external guidance systems [4]. The IVP2 system approach is described in the second part of the paper.

The main applications for these wireless videoprobes are the diagnosis of the gastro-intestinal tract, but depending on the performance of the system special applications (temporary implant, special diagnosis, etc) are feasible.

In the field of image sensor technology the CCD has been the main stream technology since more than 20 years, but CMOS image sensors gained increasingly market shares recently. CMOS (Complemetary-Metal-Oxide-Semiconductor) technology is the basis of modern microelectronics. With advanced CMOS technologies (in sub-micron dimensions) sensor pixel sizes of a few microns are feasible. Therefore image sensors with good resolution and performance could be fabricated for a reasonable price. A further advantage of this technology is the possibility to integrate additional functions.

The High-Dynamic-Range-Camera (HDRC®) [5] is a special type of CMOS image sensor with a logarithmic response of the pixel.

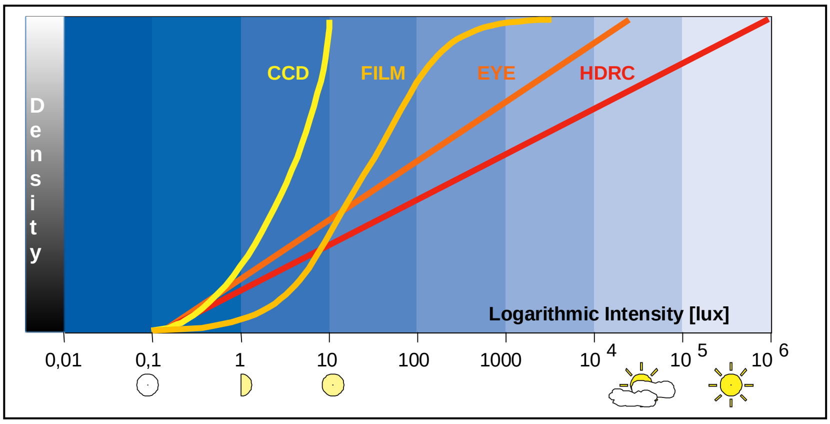

Figure 1 Response for different illumination conditions

Figure 1 shows the response versus illumination for different image detection systems. The sensitivity of the human eye is similar to a logarithmic responding of the sensor. As indicated in the Figure 1 the HDRC sensors [6] cover a wide range of illuminations (dynamic range over 120dB). Thus no mechanical shutter is necessary to avoid saturation. There is no loss of information even for very bright spots or in high contrast scenes. The sensor shows colour constancy for all displayable illumination conditions, which is very important for medical applications, where the colour information essential.

1. The Wired Videoprobe IVP1

The major objective during the development of the **IVP1 image sensor** was the size of both the image area and the overall chip. Thus additional to the general objectives three issues had to be addressed:

- The minimisation of the pixel size to allow an acceptable dimensions for this sensor.
- The reduction of the number of pad connections, because bonding pads with its area and the required sizes for pad circuitry cover a significant area of the chip. Additionally each bond requires also size on the package.
- The testability off the device to allow complete evaluation and verification of the first devices.

The resulting sensor has an image field of 200 x 180 pixels with a pixel size of 4,6 µm. The overall chip size is 1,7 x 1,3 mm^2 and the device has 4 connections. The chip is originally equipped with 43 pads, which are used for the complete digital test. The majority of these pads are cut-off before the final mounting of the chip.

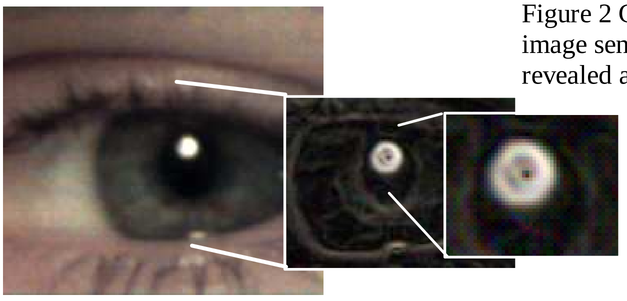

Figure 2 Colour image obtained with IVP1 image sensor. The enlarged images show details revealed after edge detection

The image sensor is coated with colour filters (red, green, blue). Figure 2 shows a colour image of a human eye obtained with an IVP1 image sensor. Although the bright reflection in the centre seems to be saturated, more details are visible in the enlarged images, which have been processed with an edge-detection software. The details are the shape of the spot light used for the illumination during the shot.

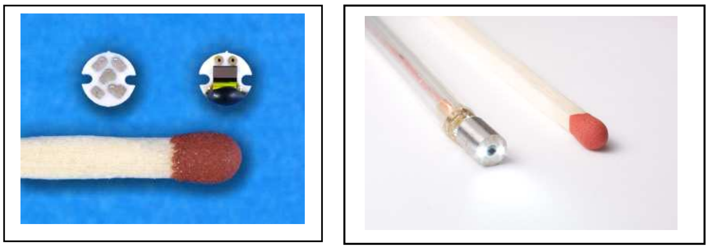

Figure 3 Ceramic board with IVP1 image sensor and pad connectors (left), IVP1 videoprobe head with optics and illumination (right)

For the fabrication of the **IVP1 prototype** the chip is mounted on a circular (Ø 3mm) ceramics (see Figure 3), where it is connected to the cables. Two openings in the circuit board are used to fix the optical fibres for the illumination: A metal cap with the optics completes the distal end of the endoscope. The analogue image data are transferred via the cables to a PC, where the image data are processed and subsequently displayed.

The prototype IVP1 has no internal **steering mechanisms** to produce tilting movements. For the first version of the video probe an external rigid pipe has been used, in order to generate an axial rotation movement into the capsule; a joint with one degree of freedom will be included in order to produce the bending movement. The pipe must be hollow for electrical wires and optical fibers connection. The external diameter of the pipe is about 3 mm. We can easily obtain movements of the tip of +/- 90 degrees.

A second prototype with a more flexible connection (rubbery multilumen tube) between the steerable tip (which includes the camera and the optical fibre) and an ergonomic handle, which allows the actuation of the steering mechanism, has been developed. In particular the diameter of the tube is 3.5 mm, moreover, in order to have a better steering angle, the distal part of the tube has a different hardness as regard with the rest of the tube itself. The steering of the tip is obtained thanks to two push-pull cables connected to the tip and actuated manually or by a motor positioned in the handle. The systems are shown in Figure 4.

For the manually actuated version, a sort of wheel can be screwed on a threaded shaft where the proximal end of the hollow pipe is fixed. As regards the motorized version, a geared motor is used to pull the push pull cables (Figure 4 c).

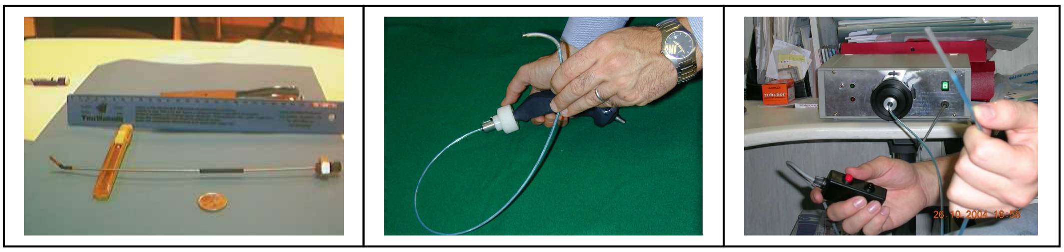

Figure 4 IVP1 steering : the movable tip (l), steering with a handle (m) , motor driven system (r)

2. The IVP2 Capsule

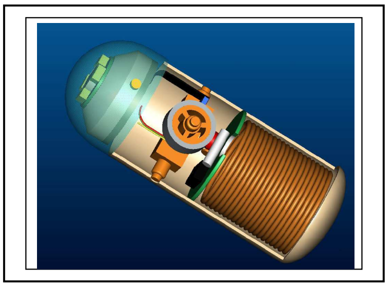

Figure 5 Scheme of the capsule

The autonomous IVP2 system (Figure 5) contains a CMOS image sensor with camera, optics and illumination, a transceiver, a system control with image data compression unit and a power supply. The optical part is located on a tiltable plate, which is driven by a wobble motor.

The **IVP2 image sensor** for the IVP2 capsule is a HDRC image sensor with a resolution of 768 x 496 pixels. The sensor has a sensitivity of 120 (digits/decade). Its dynamic range is 150dB and the minimal detectable illumination is 0.005lux. Frames are generated at 14 MHz. The has a pixel pitch of 7,4 µm. It has an integrated A/D converter. Similar to the IVP1 sensor organic colour filters are used.

This image resolution and frame rate in capsule endoscopy lead to a bottleneck problem: the data rate allowed by data transmission is too low to reach both high image resolution and high frame rate. The HDRC image sensor operated at 10 images per second will produce about 30 106 bits. On the other hand data transmitters available for capsule endoscopy can transmit between one and two megabits per second.

The solution proposed is an **image compression** dedicated for endoscopic images that meets both high compression ratio, and low power consumption. Such a result is made possible by the endoscopic image characteristics: there are mainly smooth and small changes in the image. [7]

A technique, which uses the prediction of pixels by its predecessors to reduce image size has been tested and implemented on a dedicated ASIC of 2x2 mm (Figure 6a) with a power consumption of 10mW. The comparison between an image (Figure 6.b) and the same image compressed by a factor 20 (Figure 6.c) let see the small degradation of the image quality.

Figure 6 a) chip picture, b) original picture, c) compression by 20.

The feasibility of an inductive link meeting all the power specifications imposed by capsule endoscopy is shown in previous work [8]. The **power link prototype** consists of one external coil and three internal coils, both parts equipped with their respective driver or receiver electronics.

Figure 7 External coil with class E driver

In Figure 7. a prototype of the external coil is depicted. A class E inverter feeds this coil with high amplitude currents (up to 10 A) at 1 MHz, the operation frequency of the link.

In Figure 8 the receiver part is depicted. It consists of three orthogonal coils and a stack of thick-film substrates fixating and interconnecting the receiver electronic components (Figure 8 (a)). The three coils can be slid into one another to form a compact cylinder with the electronics inside (Figure 8 (b)). Because of their orthogonallity, there is always at least one coil capable of extracting power out of the external magnetic field, no matter the orientation of the capsule.

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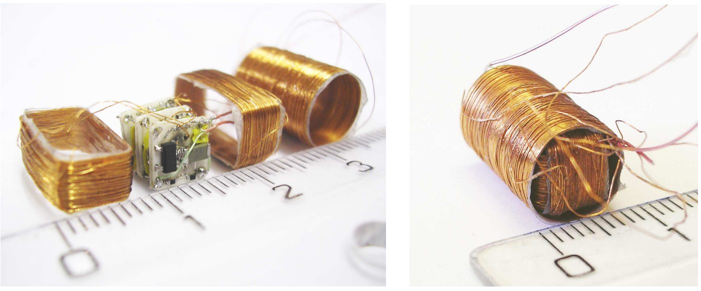

(a) (b)

Two stable DC voltages are delivered by the link output to the rest of the capsule electronics: one at 3.6 V and one at 2.5 V. The worst-case power efficiency was measured to be 1.5 % for this prototype.

Figure 8 (a) Three orthogonal coils and receiver electronics integrated on a stack of thick-film substrates. (b) Electronics and coils assembled for integration in capsule

The basic concept is to use a frontal view system with a vision angle upper to 120 degrees and a **tilting mechanism** able to steer the vision system (optics, illumination and image sensor) between about ± 30 degrees in one plane. By exploiting this technique, the device will perform an optimal view between ± 90 degrees in the xy plane. The tilting mechanism can be realized by using a wobble motor (the Q-PEM motor) and simple mechanical parts, such as one cam and one shaft fixed to the vision system.

The cam system transforms the rotational action of the motor in a linear action to the shaft. The vision system can be tilted by the shaft if two diametrically opposed points of the vision system itself are fixed to the body capsule. The entire system, including optic and electronic components, will be inserted in the capsule body.

The Q-PEM motor can be controlled with a precision of 300 steps for each complete round. A motor with overall dimensions of 4 mm of diameter and 3 mm of thickness has been designed and realized (see Figure 9).

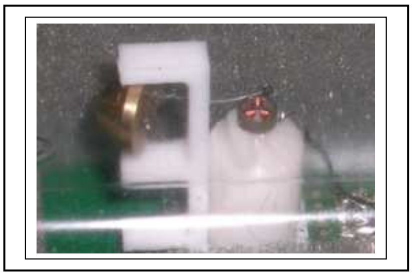

Figure 9 Wobble motor for the tilting movement of the camera head

The main objective of the "**expert system**" subsystem is to increase the expert's ability in identifying suspicious regions and decrease the need for intervention while maintaining the ability for accurate diagnosis. Computer-assisted image analysis can extract the representative features of the images together with quantitative measurements and thus can ease the task of objective interpretations by a physician expert in endoscopy. The proposed methodology is considered in two phases. The first implements the extraction of image features while in the second phase an advanced neural network is implemented / employed to perform the diagnostic task. Texture analysis is one of the most important features used in image processing and pattern recognition. It can give information about the arrangement and spatial properties of fundamental image elements. The definition and extraction of quantitative parameters from endoscopic images based on texture information in the chromatic and achromatic domain is being proposed. This information is initially represented by a set of descriptive statistical features calculated on the histogram of the original image. For this reason, we focused our attention on nine statistical measures (standard deviation, variance, skew, kurtosis, entropy, energy, inverse difference moment, contrast, and covariance) [9]. All texture descriptors are estimated for all planes in both RGB {R (Red), G (Green), B (Blue)} and HSV {H (Hue), S (Saturation), V (Intensity)} spaces, creating a feature vector for each descriptor $D_i=(R_i,G_i,B_i,H_i,S_i,V_i)$. Thus, a total of 54 features (9 statistical measures x 6 image planes) are then estimated. In addition to the classic "histogram"-based approach, an alternative approach of obtaining those quantitative parameters from the texture spectra is proposed both in the chromatic and achromatic domains of the image. The definition of texture spectrum employs the determination of the texture unit (TU) and texture unit number (N_{TU}) values. Texture units characterise the local texture information for a given pixel and its neighbourhood, and the statistics of the entire texture unit over the whole image reveal the global texture aspects [10].

For the diagnostic part, the concept of multiple-classifier scheme has been adopted, where the fusion of the individual outputs was realised using fuzzy integral [11] (see Figure 10).

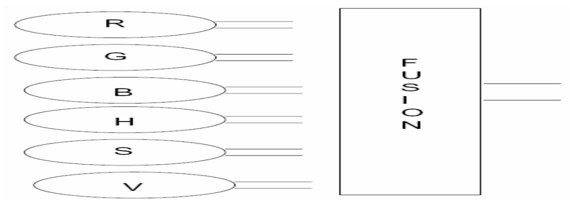

Figure 10 Proposed fusion scheme.

An intelligent classifier-scheme based on the methodology of Extended Normalised Radial Basis Function (ENRBF) neural networks has been also implemented [12] (see Figure 11).

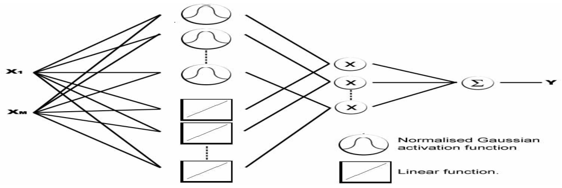

Figure 11: ENRBF scheme.

3. Summary

The two videoprobes to be demonstrated in the IST-project IVP have been presented with its special features. The results show the feasibility of miniaturised video-endoscopes for many medical and technical applications. The major components of the autonomous capsule such as image sensor with the data compression for digital data transmission, the power system, a micro-mechanical tilting mechanism and the expert system have been developed.

Acknowledgement

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