The Data-acquisition, Processing and Control System of a Micromirror-based Laser-scanning Endoscope

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ABSTRACT

A novel endoscope device has been developed based on a new technology of laser scanning using silicon micromirrors for superior resolution and chromatic representation compared with the existing endoscopes. A critical part of this device, that is reported here, is the data- acquisition, control and processing (DACP) system which acquires, processes, displays, stores in real-time the collected images and handles the control signals. The software developed uses the multithreading technology for the parallel execution of specific software tasks in the available CPUs of the multiprocessing system employed. In this manner, the necessary computational power is provided for the realization of a high-performance real-time imaging system. First-trial results are also given.

1. INTRODUCTION

The contemporary endoscopic systems, providing a continuous vision of otherwise inaccessible regions, allow extremely localized diagnosis with practically no risk for the patient because of its quasi-non-invasive nature [1,2]. A number of technologies currently exist for the flexible endoscopes, which vary according to the illumination and detection principles followed. This paper is focused to the electronic and processing part of a novel endoscope device that provides color imaging at near-video frame rates with enhanced resolution attributes, compared to the existing ones, using a new technology that is based on micromirrors of MEMS (Micro Electro Mechanical Systems) type for the laser-scanning operation [5], [6], [7]. One of the principal and improving factors for the exploitation of this new technology is the data-acquisition, processing and control system developed by our group as an integral part of the endoscope device. In the present paper, after a brief description of the general characteristics of the endoscope device and the micromirrors employed, we present main information about the above electronic and signal processing system.

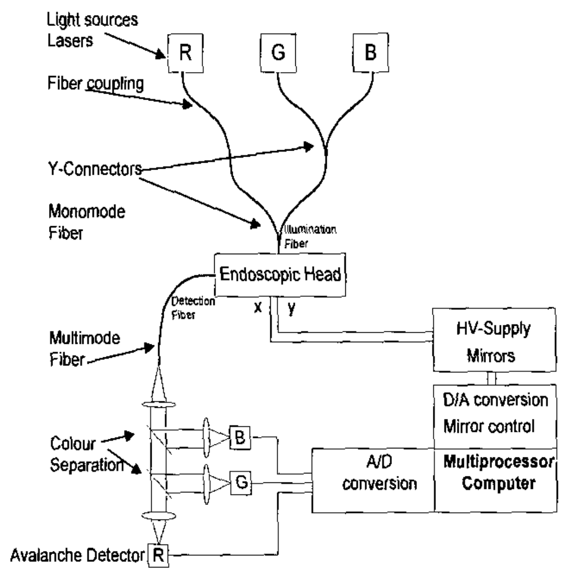

Fig. 1: System concept of the microscanning endoscope

2. DESCRIPTION OF THE MICROSCANNING ENDOSCOPE DEVICE

The overall set-up concept is presented in Fig.1. Emanating from the illumination subsystem, three laser beams with wavelengths in the red (655 nm), green (532 nm) and blue (473 nm) spectrum are collimated and guided through a multimode fiber to the endoscope tip, which is the distal part of the endoscope device that is inserted inside the patient's body. This tip plays the role of a point source for the three laser beams illuminating the target tissue and also collects the back-reflected/scattered light with the associate optics and a light-collection fiber. Inside the tip, micro-optical components have been integrated for the focusing and guiding of the illuminating and detected light together with the separation of the illumination and detection optical paths and stray light rejection.

The two microscanning (micro)mirrors have been constructed using a novel MEMS technology. The micromirrors can be deflected electrostatically in directions orthogonal each to another, in accordance with the high-voltage signals applied from the control subsystem. These micromirors are used for the scanning and descanning of the composite laser beam on the target object and the backscattered light respectively in a raster mode of operation.

The backscattered optical signal from the scanning "flying spot" is collected with an optical assembly inside the microscanning tip and sent to the detection fiber. The so-collected backscattered signal is guided through the fiber to the optical detection unit that is based on specific avalanche photodiodes. The data acquisition board digitizes simultaneously the three electrical signals (one for each color) at the output of the optical detection unit and also generates the waveforms that control the scanning mirrors. The software that has been developed, programs the data acquisition board, generates through this card the appropriate scanning waveforms, receives the samples data stream and reconstructs, displays and stores the associated two-dimensional images for further processing and analysis in real-time. Various specifications of the realized microscanning endoscope are presented in Table 1.

3. MICROMMIROR DESIGN AND FABRICATION

The use of bulk silicon technology for the fabrication of electrostatically driven torsional micromirrors has appeared rather frequently in technical literature [3,4]. The major disadvantage of this kind of micromirrors is their fragility that prevents their extended use in practical applications. The micromirrors designed, fabricated and tested for the present scanning device are more compact and can meet the requirements of fast two-dimensional scanning with large scan angles and high shock resistance. This is achieved by combining bulk silicon technology with metal surface micromachining. In Fig.2 a photograph of a scanning micromirror is given. The first micromirror, having a size of 3x4 mm^2, is used for the line scanning operation and is driven in a resonant mode at about 1.2 kHz in order to achieve the maximum possible mirror deflection. The second mirror, set in a serial arrangement, has a size of 4x4.8 mm^2 and is used for the frame scanning operation in a sawtooth-like sweep. Both mirror types, the slow axis mirror as well as the fast axis mirror are capable of mechanical deflections of ±3°.

Table 1: Microscanning endoscope specifications

Maximum resolution [lp/mm]:	16
Maximum overall diameter (mm)	11
Fast mirror scanner size (mmxmm)	3x4
Fast mirror mechanical angle (°)	±3
Fast mirror resonant frequency (kHz)	1.2
Fast mirror curvature (nm)	<80
Slow mirror scanner size (mmxmm)	4x4.8
slow mirror mechanical angle (°)	±3
slow mirror curvature (nm)	<80

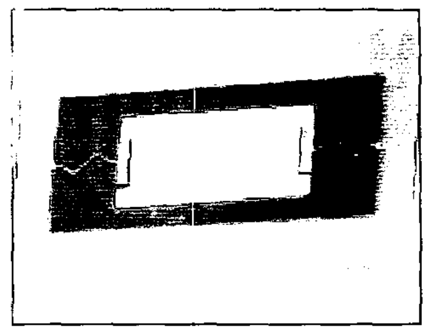

Fig.2: Silicon mirror plate and Nickel suspensions

4. THE DATA-ACQUISITION, CONTROL AND PROCESSING (DACP) SYSTEM

The data-acquisition control and processing system of the entire device is depicted by the block diagram of Fig. 3. The DACP system simultaneously digitizes the three electrical signals (one for each color) generated from the optical detection of the backscattered light signal and generates the two analog waveforms needed for the position control of the scanning micromirrors used. After digitization, the reconstruction, preprocessing and display operations are performed in real-time with the multiprocessor PC system employed.

The principal module of the data-acquisition and control subsystem is the PCI-6110E card of National Instruments Co. With this card, the simultaneous digitization of the three analog signals is performed at 5 Msamples/sec with 12-bit resolution. Also the generation of the control waveforms is performed using the available D/As at an update rate of 2.5 Msamples/sec on both channels simultaneously with a 16-bit resolution.

The PC platform used is a Symmetric Multiprocessor (SMP) system with two PENTIUM-III CPUs , 256 MB SDRAM and two SCSI Hard disk drives in a RAID-0 configuration. The operating system under use was the Microsoft Windows NT 4.0 in its multiprocessing version that supports the parallel execution of the program developed into the available processors. The software for the microscanning system has been developed as a multithreaded program ensuring predictable responsiveness to events and commands through the user

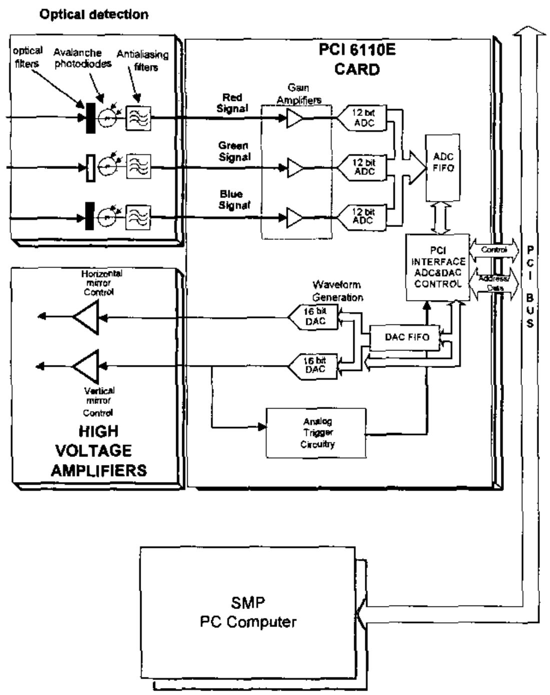

Fig. 3: The data acquisition and control system

interface, while its parallel execution into the available CPUs provides increased processing power for real-time performance. After digitization the images are reconstructed and displayed in one window of the GUI's main panel. The raw images are enhanced by pre-processing with specific algorithms and are displayed in the second window of the GUI's main panel and stored in an array of hard disks for further analysis. The GUI developed with the two windows can be seen in Fig. 4. The preprocessing, display and storage operations are all performed in real-time. The overall data transfer rate from the data acquisition card to the PC memory is 30 MB/sec through the PCI bus. Also, the data rate transferred simultaneously from the PC memory subsystem to the D/A section of the acquisition card is 10 MB/sec through the PCI bus and the data rate of the storage operation in the two hard disks is 30 MB/sec through the SCSI bus. The multithreaded software developed is capable of handling all these processes in real-time while at the same time displays the color images in one window of the user interface developed at rates of up to 20 frames/sec with resolution of 500x500 pixels and the post-processing and display of these images with the same resolution in the second window of the GUI's main panel.

The software for the DACP system was developed using the integrated development environment C-Builder 4.0 from Borland Co. The programming of the PCI6110E data-acquisition card was based on the accompanying library NIDAQ 6.06 from National Instruments Co. This library provides the necessary Dynamic Link Library drivers for the Windows NT operating system for the control of the data acquisition and the waveform generation procedures. The preprocessing of the acquired images in real-time is based on the Image Processing Library developed by Intel Co. This library is written in assembly language and takes full advantage of the processor's MMX instruction set. The preprocessing operations normally performed are: a)bi-directional rearrangement due to the bi-directional scanning procedure b) look-up table transformation for the three colors and c) spatial convolution filtering according to the user needs. For the real-time display of the acquired images a routine has been developed that uses the Microsoft DirectX 7.0 technology for direct access of the local memory of the video graphics card employed.

The developed control software generates the two waveforms which, after being amplified by the high-voltage module, drive the micromirrors used for the scanning operation. For the horizontal (line) mirror a sinusoidal waveform is produced at the frequency of mechanical resonance, while a triangular waveform is generated for control of the vertical (frame) mirror. As the generation of these two waveforms is asynchronous to the execution of the other software tasks, it is activated by a call to this task, programmed for infinite iterations, and then the control is returned to the other tasks. Once the waveform generation has been activated it can be paused or stopped only by another call to this task. The waveforms are synthesized using appropriate algorithms according to the physical characteristics of the mirrors and the user requirements.

The data-acquisition software module was designed as an asynchronous event-driven process in which the data are temporarily stored into the main memory using the DMA technique with minimum CPU intervention. The analog trigger capability of the data acquisition board has been utilized in order to synchronize the data acquisition process with the movement of the scanning mirrors. More specifically the control signal of the vertical mirror has been connected with the analog trigger input in order to event-drive the data acquisition process.

5. RESULTS

As a result of the present work, a compact microscanning endoscope prototype has been designed, assembled and tested in operational conditions. In Fig. 4 the main GUI panel of the software is presented from system operation with scanning a heart tissue in vitro. The left window refers to the raw images while the right one refers to the processed images. The field of view was 11x11 mm^2 while the resolution of the entire system was of the order of 50 μm depending on the design of the collimating lens and the collecting fiber.

6. COMMENTS AND CONCLUSIONS

Compared to the existing commercial endoscopes the

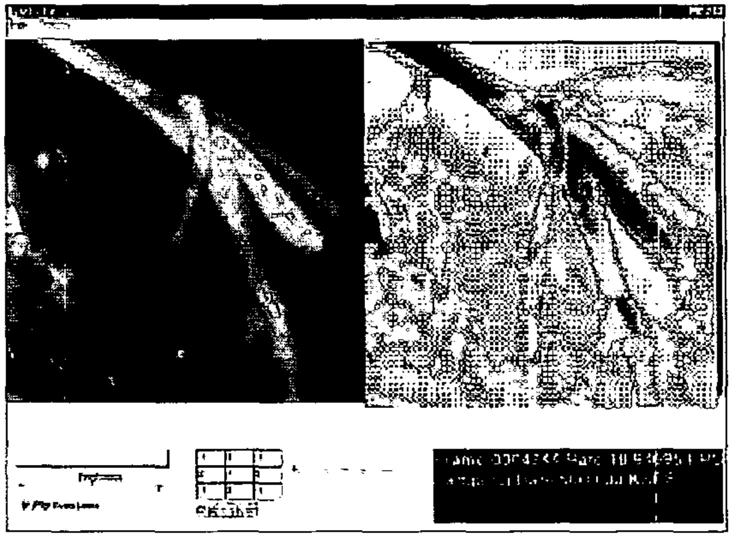

Fig. 4: The main panel of the GUI developed showing part of a heart tissue (in vitro)

present microscanning endoscope offers a number of advantages among which the increased resolution that is almost double to approximately 20 line pairs/mm. This has been achieved by avoiding color dispersion problems and using a new technology for endoscope imaging and a novel data processing and control system.

The supporting data acquisition, control and processing system and software ensures enhanced signal handling and enables the microscanning endoscope operation in real-time conditions. The multithreading technology was fully exploited for utilizing the available processing power of the SMP system used. The overall software has been designed as an asynchronous event-driven process capable of retaining synchronization with the open loop control scheme followed, while its modular architecture has permitted the easy debugging and adaptation of the system to the modifications needed during the development and testing phases of the device. The data-acquisition, control and processing system presented acquires, reconstructs and displays the collected color images of 500x500 pixels with 12-bit resolution at rates up to 20 frames/sec, and post-processes and displays these images in a second window of the GUI's main panel in real-time. In addition and simultaneously the software developed is capable of generating the two control waveforms of the scanning micromirrors and stores the collected images in an array of hard disks. The described techniques followed for the development of the data acquisition, control and processing system of the microscanning endoscope can be easily adapted for the development of other similar-type high-performance imaging systems, especially in the medical field.

7. ACKNOWLEDGMENTS

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