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IMAGE SENSORS IN SECURITY AND MEDICAL APPLICATIONS

Evgeny Artyomov, Alexander Fish, Orly Yadid-Pecht

***Abstract**: This paper briefly reviews CMOS image sensor technology and its utilization in security and medical applications. The role and future trends of image sensors in each of the applications are discussed. To provide the reader deeper understanding of the technology aspects the paper concentrates on the selected applications such as surveillance, biometrics, capsule endoscopy and artificial retina. The reasons for concentrating on these applications are due to their importance in our daily life and because they present leading-edge applications for imaging systems research and development. In addition, review of image sensors implementation in these applications allows the reader to investigate image sensor technology from the technical and from other views as well.*

***Keywords:** CMOS image sensors, low-power, security applications, medical applications.*

***ACM Classification Keywords:** B.8.1.i Hardware - Integrated Circuits - Types and Design Styles - VLSI*

1. Introduction

Fast development of low-power miniature CMOS image sensors triggers their penetration to various fields of our daily life. Today we are commonly used to meet them in digital still and video cameras, cellular phones, web and security cameras, toys, vehicles, factory inspection systems, medical equipment and many other applications (see Figure 1). The advantages of current state-of-the-art CMOS imagers over conventional CCD sensors are the possibility in integration of all functions required for timing, exposure control, color processing, image enhancement, image compression and analog-to-digital (ADC) conversion on the same chip. In addition, CMOS imagers offer significant advantages in terms of low power, low voltage, flexibility, cost and miniaturization. These features make them very suitable especially for security and medical applications. This paper presents a review of image sensors utilization in part of the security and the medical applications.

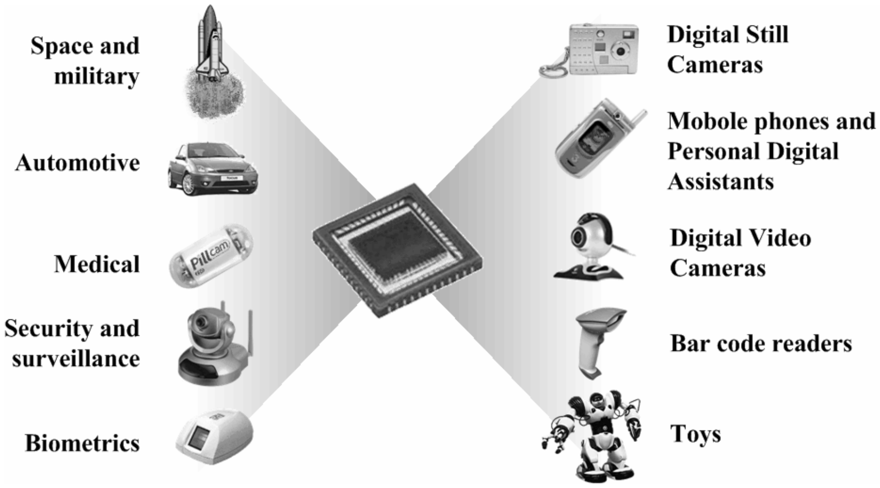


Figure 1. Image sensors applications

During the last few years imaging systems for security applications have been significantly revolutionising. Large, high cost and inefficient cameras mostly used for specific military and government applications have been replaced with compact, low-cost, low-power smart camera systems, becoming available not only for military and government, but for wide spreading in civilian applications. In this paper we will concentrate on two major categories: (a) surveillance systems – usually used for observation, anomaly detection and alarming, employing one or multiple cameras, (b) biometrics systems – used for access control and person identification. Each of the presented categories requires sensors having different specifications: for example, while low-power and compactness are the most important features for some surveillance systems, robustness and high image quality are the most important requirement in biometric systems.

Medical applications also benefit from the fast image sensors technology development. Introduction of miniature, ultra-low power CMOS image sensors have opened new perspectives to minimally-invasive medical devices, like wireless capsules for gastrointestinal tract observation [1]. Here we will review two very important medical applications:

(a) artificial retina – used as an artificial replacement or aid to the damaged human vision system,

(b) wireless capsule endoscopy – used in minimally invasive gastrointestinal tract diagnostics.

The remainder of the paper is organized as follows: Section II briefly presents CMOS image sensor technology with reference to "smart" CMOS image sensor architecture. The role of image sensors in security applications is described in Section III. Section IV reviews medical applications employing state-of-the-art CMOS imagers. Section V concludes the paper.

2. CMOS Image Sensor Technology in a Glance

The continuous advances in CMOS technology for processors and DRAMs have made CMOS sensor arrays a viable alternative to the popular charge-coupled devices (CCD) sensor technology. Standard CMOS mixed-signal technology allows the manufacture of monolithically integrated imaging devices: all the functions for timing, exposure control and ADC can be implemented on one piece of silicon, enabling the production of the so-called “camera-on-a-chip” [2]. Figure 2 is a diagram of a typical digital camera system, showing the difference between the building blocks of commonly used CCD cameras and the CMOS camera-on-a-chip [3]. The traditional imaging pipeline functions—such as color processing, image enhancement and image compression—can also be integrated into the camera. This enables quick processing and exchanging of images. The unique features of CMOS digital cameras allow many new applications, including network teleconferencing, videophones, guidance and navigation, automotive imaging systems, robotic and machine vision and of course, security and bio-medical image systems.

Most digital cameras still use CCDs to implement the image sensor. State-of-the-art CCD imagers are based on a mature technology and present excellent performance and image quality. They are still unsurpassed for high sensitivity and long exposure time, thanks to extremely low noise, high quantum efficiency and very high fill factors. Unfortunately, CCDs need specialized clock drivers that must provide clocking signals with relatively large amplitudes (up to 10 V) and well-defined shapes. Multiple supply and bias voltages at non-standard values (up to 15 V) are often necessary, resulting in very complex systems.

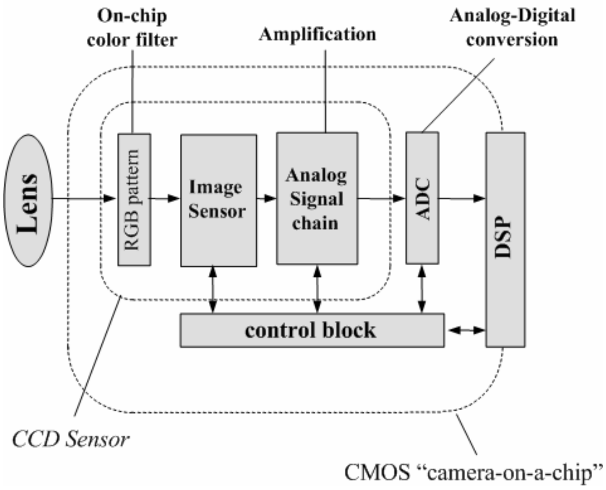


Figure 2. Block diagram of a typical digital camera system.

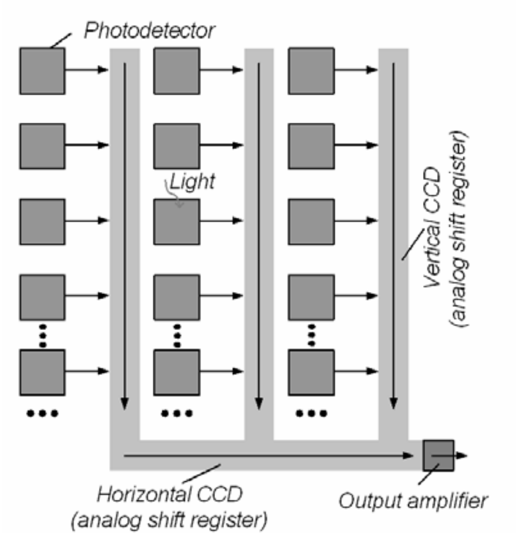


Figure 3. Block diagram of a typical interline transfer CCD image sensor.

Figure 3 is a block diagram of a widely used interline transfer CCD image sensor. In such sensors, incident photons are converted to charge, which is accumulated by the photodetectors during exposure time. In the subsequent readout time, the accumulated charge is sequentially transferred into the vertical and horizontal CCDs and then shifted to the chip-level output amplifier. However, the sequential readout of pixel charge limits the readout speed. Furthermore, CCDs are high-capacitance devices and during readout, all the capacitors are switched at the same time with high voltages; as a result, CCD image sensors usually consume a great deal of power. CCDs also cannot easily be integrated with CMOS circuits due to additional fabrication complexity and increased cost. Because it is very difficult to integrate all camera functions onto a single CCD chip, multiple chips must be used. A regular digital camera based on CCD image sensors is therefore burdened with high power consumption, large size and a relatively complex design; consequently, it is not well suited for portable imaging applications.

Unlike CCD image sensors, CMOS imagers use digital memory style readout, using row decoders and column amplifiers. This readout overcomes many of the problems found with CCD image sensors: readout can be very fast, it can consume very little power, and random access of pixel values is possible so that selective readout of windows of interest is allowed. The power consumption of the overall system can be reduced because many of the supporting external electronic components required by a CCD sensor can be fabricated directly inside a CMOS sensor. Low power consumption helps to reduce the temperature (or the temperature gradient) of both the sensor and the camera head, leading to improved performance.

An additional advantage of CMOS imagers is that analog signal and digital processing can be integrated onto the same substrate, allowing fabrication of so called "smart" image sensors. Many "smart" image sensors have already been demonstrated in the literature. They performed functions of real time object tracking [4]-[11], motion detection [12]-[13], image compression [14]-[15], widening the dynamic range of the sensor [16]-[20] and others. These functions are usually performed by digital or nonlinear analog circuits and can be implemented inside the pixels and in the periphery of the array. Offloading signal processing functions makes more memory and DSP processing time available for higher-level tasks, such as image segmentation or tasks unrelated to imaging.

CMOS pixels can be divided into two main groups, passive pixel sensors (PPS and active pixel sensors (APS). Each individual pixel of a PPS array has only a photosensing element (usually a photodiode) and a switching

MOSFET transistor. The signal is detected either by an output amplifier implemented in each column or by a single output for the entire imaging device. These conventional MOS-array sensors operate like an analog DRAM, offering the advantage of random access to the individual pixels. They suffer from relatively poor noise performance and reduced sensitivity compared to state-of-the-art CCD sensors. APS arrays are relatively novel image sensors that have amplifiers implemented in every pixel; this significantly improves the noise parameter.

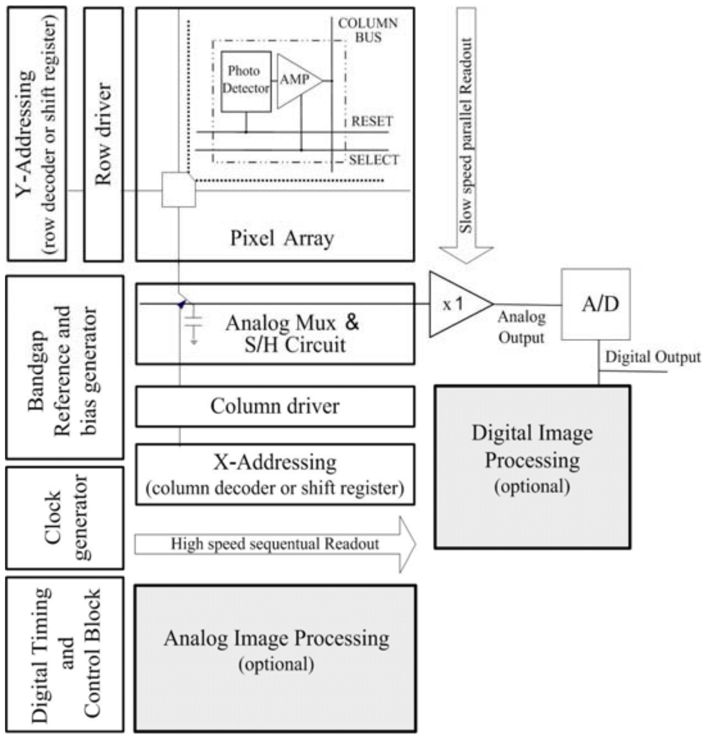


Figure 4. General architecture of the "smart" CMOS APS based image sensor.

Figure 4 shows the general architecture of the "smart" CMOS APS based image sensor. The core of this architecture is a camera-on-a-chip, consisting of a pixel array, a Y-addressing circuitry with a row driver, an X-addressing circuitry with a column driver, an analog front end (AFE), an analog-to-digital converter (ADC), a digital timing and control block, a bandgap reference and a clock generator. Optional analog and digital processing blocks "upgrade" the camera-on-a-chip core to a "smart" imager, and they are used to perform additional functions, that can vary from design to design, depending on the application and system requirements.

The basic imager operation, depends on the chosen photodetector and pixel types, readout mode, Y-addressing and X-addressing circuitries, ADC type and of course, the analog and/or digital image processing. A brief description of the main imager building blocks is presented herein.

A. *APS Pixel Array* – the imager pixel array consists of N by M active pixels, while the most popular is the basic photodiode APS pixel, employing a photodiode and a readout circuit of three transistors. Generally, many types of photodetectors and pixels can be found in the literature. This includes a p-i-n photodiode, photogate and pinned photodiode based pixels, operating either in rolling shutter or in global shutter (snapshot) readout modes. The difference between these modes is that in the rolling shutter approach, the start and end of the light collection for each row is slightly delayed from the previous row, leading to image distortion when there is relative motion between the imager and the scene. On the other hand, the global shutter technique uses a memory element inside each pixel and provides capabilities similar to a mechanical shutter: it allows simultaneous integration of the entire pixel array and then stops the exposure while the image data is read out. A detailed description of both rolling shutter and global shutter pixels can be found in [3].

Note, although most of today's "cameras-on-a-chip utilize" very simple pixels, many "smart" imagers employ more complicated pixels. Some of them perform analog image processing tasks at the pixel level. Very good examples for these imagers are neuromorphic sensors, where each pixel consists of a photo detector and local circuitry, performing spatio-temporal computations on the analog brightness signal. Another example is an imager, where the A/D conversion is performed in the pixel level.

B. Scanning Circuitry – Unlike CCD image sensors, CMOS imagers use digital memory style readout, usually employing Y-Addressing and X-Addressing to control the readout of output signals through the analog amplifiers and allow access to the required pixel. The array of pixels is accessed in a row-wise fashion using the Y-Addressing circuitry. All pixels in the row are read out into column analog readout circuits in parallel and then are sequentially read out using the X-Addressing circuitry (see Figure 4).

C. Analog Front End (AFE) - all pixels in a selected row are processed simultaneously and sampled onto sample-and-hold (S/H) circuits at the bottom of their respective rows. Due to this column parallel process, for an array having M columns, the AFE circuitry usually consists of 2*M S/H circuits, M size analog multiplexer, controlled by the X-Addressing circuitry, and one or M amplifiers to perform correlated double sampler (CDS). The CDS improves the signal-to-noise ratio (SNR) by eliminating the fixed pattern noise (FPN). A programmable- (or variable-) gain amplifier (PGA or VGA) follows the CDS to amplify the signal and better utilize the full dynamic range of the A/D converter (ADC).The number of amplifiers, required to perform the CDS functionality depends on the chosen CDS architecture and is equal to 2*N in case the subtraction is done separately for each column. The choice of an AFE configuration depends on many factors, including: the type of sensor being used, dynamic range, resolution, speed, noise, and power requirements. The considerations regarding making appropriate AFE choices for imaging applications can be found in [21].

D. Analog-to-digital conversion (ADC) – ADC is the inherent part of state-of-the-art "smart" image sensors. There are three general approaches to implementing sensor array ADC:

1. Pixel-level ADC, where every pixel has its own converter [22]-[23]. This approach allows parallel operation of all ADCs in the APS array, so a very low speed ADC is suitable. Using one ADC per pixel has additional advantages, such as higher SNR and simpler design.

2. Column-level ADC, where an array of ADCs is placed at the bottom of the APS array and each ADC is dedicated to one or more columns of the APS array [24]-[25]. All these ADCs are operated in parallel, so a low-to-medium-speed ADC design can be used, depending on the sensor array size. The disadvantages of this approach are the necessity of fitting each ADC within the pixel pitch (i.e., the column width) and the possible problems of mismatch among the converters at different columns.

3. Chip-level ADC, where a single ADC circuit serves the whole APS array [26]-[27]. This method requires a very high-speed ADC, especially if a very large array is used. The architecture shown in Figure 4, utilizes this approach for ADC implementation.

E. Bandgap reference and current generators – these building blocks are used to produce on-chip analog voltage and current references for other building blocks like amplifiers, ADC, digital clock generator and others. It is very important to design high precision and temperature independent references, especially in high resolution state-of-the-art image sensors, where the temperature of the die can vary by many tens of degrees.

F. Digital timing and control block, clock generator - aim to control the whole system operation. Their implementation in the chip level decreases the number of required I/O pads and thus reduces system power dissipation. Synchronized by the generated clock, the digital timing and control block produces the proper sequencing of the row address, column address, ADC timing and the synchronization pulses creation for the pixel data going offchip. In addition, it controls the synchronization between the imager and the analog and digital processing.

G. Analog and Digital Image Processing – although these blocks are optional, they play a very important role in today's "smart" image sensors. Conventional vision systems are put at a disadvantage by the separation between a camera for “seeing” the world, and a computer or DSP for “figuring out” what is seen. In these systems all information from the camera is transferred to the computer for further processing. The amount of processing circuitry and wiring necessary to process this information completely in parallel is prohibitive. In all engineered systems, such computational resources are rarely available and are costly in terms of power, space, and reliability. Opposite to a conventional camera-on-a-chip, which only captures the image and transfer it for the further processing, "smart" image sensors reduce the computational cost of the processing stages interfaced to it by carrying out an extensive amount of computation at the focal plane itself (analog and digital image processing blocks in Figure 4), and transmitting only the result of this computation (see Figure 5).

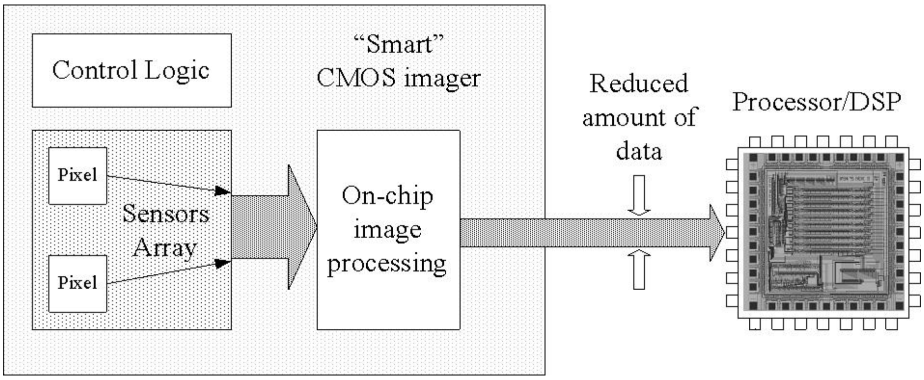


Figure 5. An example of an imaging system, employing a "smart" CMOS image sensor with on-chip processing and processors/DSPs for image processing

Both analog and digital processing can be performed either in the pixel or in the array periphery. There are advantages and disadvantages for both methods. In-pixel digital image processing is very rare because it requires pixel-level ADC implementation and results in very poor fill factor and large pixel size. In-pixel analog image processing is very popular, especially in the field of neuromorphic vision chips. In these chips in-pixel computations are fully parallel and distributed, since the information is processed according to the locally sensed signals and data from pixel neighbors. Usually, neuromorphic visual sensors have very low-power dissipations due to their operation in the subthreshold region, but suffer from low resolution, small fill-factor and very low image quality. Other applications employing in-pixel analog processing are tracking chips, wide dynamic range sensors, motion and edge detection chips, compression chips and others. The periphery analog processing approach assumes that analog processing is performed in the array periphery without penalty on the imager spatial resolution and it is usually done in a column parallel manner. While this approach has computational limitations compared to in-pixel analog processing, it allows better image quality. Periphery digital processing is the most standard and usually simpler. It is performed following the A/D conversion, utilizes standard existing techniques for digital processing and is usually done on the chip level. The main disadvantage of this approach is its inefficiency by means of area occupied and power dissipation. Note, all mentioned techniques can be mixed and applied together on one chip to achieve better results.

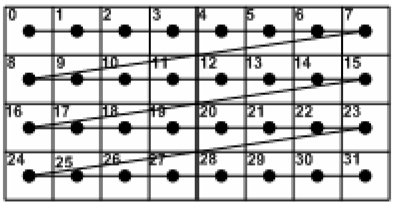
3. Image Sensors in Security Applications

The importance of security applications has significantly increased due to numerous terrorists' attacks worldwide. This area also greatly benefits from the achievements in the image sensors field. Today we can meet the cameras not only in military applications, but also in commercial and civilian applications. They are present in the shops and on the streets, in the vehicles and on the robots. The applications are numerous and can not be covered in this short paper. We have decided to concentrate on two important applications that represent a large fraction of the total security market. These applications are surveillance and biometrics. Both of the applications are extensively utilized in military, commercial and civilian fields.

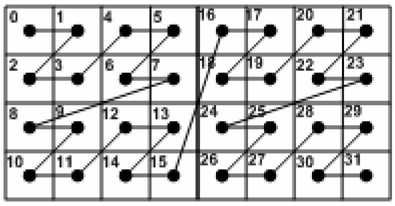
3.1 Surveillance

Surveillance systems enable a human operator [28] to remotely monitor activity over large areas. Such systems are usually equipped with a number of video cameras, communication devices and computer software or some kind of DSP for real-time video analysis. Such analysis can include scene understanding, attention based alarming, colour analysis, tracking, motion detection, windows of interest extraction etc. With recent progress in CMOS image sensor technology and embedded processing, some of the mentioned functions and many others can be implemented in dedicated hardware, minimizing system cost and power consumption. Of course, such integration affects system configurability, but not all applications require configurable systems: some of them benefit from low cost and low power dedicated hardware solutions.

For example, in [29] we have presented an image sensor that can be used for such applications. Due to a specific scanning approach this sensor can be used efficiently for motion detection, tracking, windowing and digital zoom. Figure 6 shows the standard approach for sensor data scan - raster and the alternative – Morton or Z scan.



(a) raster scan – conventional approach in image sensors,



(b) Morton (Z) scan – newly proposed and implemented

Figure 6. Two approaches for data scan

The Morton (Z) scan poses a very valuable feature, neighbor pixels that are concentrated in blocks appear at the output sequentially, one after other. With this scanning approach the image blocks can be easily extracted and processed with simple on-chip hardware. For example, for constructing video camera with $\times 4$ digital zoom, the blocks of 4×4 pixels need to be extracted and averaged. Similarly, cameras with digital zoom $\times 8$ and $\times 16$ can be easily constructed. Figure 7 shows measurements from our test chip.

Figure 7. Morton scan chip test results

Another example is a wide dynamic range (WDR) imager. Dynamic range (DR) quantifies the ability of a sensor to image highlights and shadows. If we define the dynamic range of the sensor as 20log(S/N), where S is the maximal signal value and N is the sensor noise, the typical image sensors will have a very limited dynamic range, about 65-75 dB. Wide dynamic range imaging is very important in many surveillance systems. The dynamic range can be increased in two ways: the first one is noise reduction and thus enabling expansion of the dynamic range toward darker scenes; the second method is incident light saturation level expansion, thus improving the dynamic range toward brighter scenes.

Herein we present one of the possible solutions for dynamic range extension in CMOS Active Pixel Sensors (APS) [2]. As in a traditional CMOS APS, this imager is constructed of a two-dimensional pixel array, with random pixel access capability and row-by-row readout rolling shutter method. Each pixel contains an optical sensor to receive light, a reset input and an electrical output representing the illumination received. This imager implements a simple function for saturation detection, and is able to control the light exposure time on a pixel-by-pixel basis, resulting in no saturation. The pixel value can then be determined as a floating-point representation. To do so, the outputs of a selected row are read out through the column-parallel signal chain, and at certain points in time are also compared with an appropriate threshold value, as shown in Figure 8. If a pixel value exceeds the threshold, i.e. the pixel is expected to be saturated at the end of the exposure time; the reset is given at that time to that pixel. The binary information concerning the reset (i.e., if it is applied or not) is saved in a digital storage for later calculation of the scaling factor. Thus, we can represent the pixel output in the following floating-point format: $M \cdot 2^{EXP}$, where the mantissa (M) represents the digitized pixel value and the exponent (EXP) represents the scaling factor. This way a customized, linear, large increase in the dynamic range is achieved.

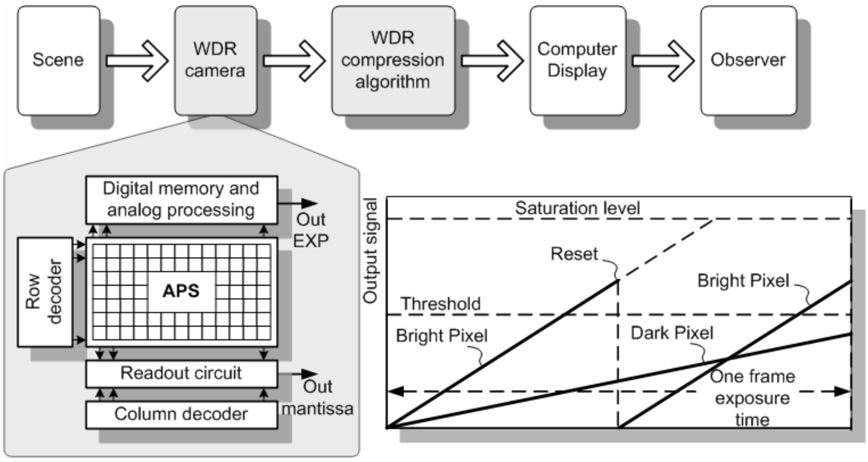


Figure 8. Imaging pipeline, image sensor architecture and work principle.

Figure 9(a) and Figure 9(b) show a comparison between an image captured by a traditional CMOS imager and by the autoexposure system described here. In Figure 9(a), a scene is imaged with a strong light hitting the object; hence, some of the pixels are saturated. At the bottom of Figure 9(b), the capability of the autoexposure sensor for imaging the details of the saturated area in real time may be observed. Since the display device is limited to eight bits, only the most relevant eight-bit part (i.e., the mantissa) of the thirteen-bit range of each pixel is displayed here. The exponent value, which is different for different areas, is not displayed.

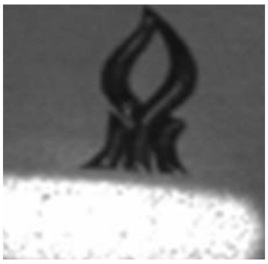


Figure 9. (a) Scene observed with a traditional CMOS APS sensor,

Figure 9. (b) Scene observed with our in-pixel autoexposure CMOS APS sensor.

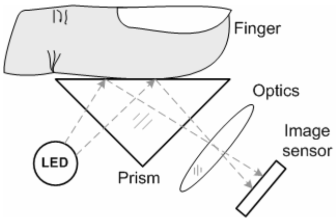
3.2 Biometric personal identification

Biometric personal identification is strongly related to security and it refers to “identifying an individual based on his or her distinguishing physiological and/or behavioral characteristics (biometric identifiers)” [30]. Figure 10 shows the most frequently used biometric characteristics.

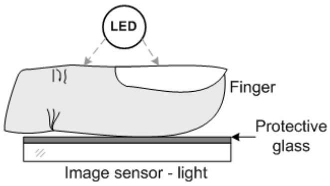
Figure 10. Biometric characteristics

Almost all biometric characteristics, shown in Figure 10, require some kind of sensing. Usually, conventional image sensors with external hardware or software image processing are used. The difficulty for on-chip integration is caused by the complexity of the required image processing algorithms. However, there are some developments that successfully achieve the required goals by parallel processing utilization.

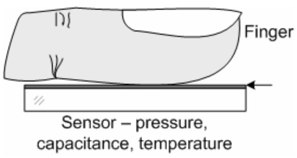
To give some more detailed examples in the field, we concentrate on fingerprint sensors. Generally these sensors can be classified by the physical phenomena used for sensing: optical, capacitance, pressure and temperature. The first two classes are the most popular and both mainly employ CMOS technology.



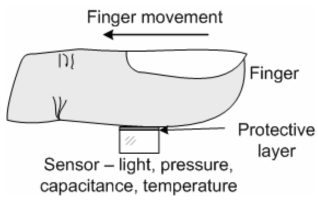
(a) optical - reflection based sensor



(b) optical – transmission based sensor



(c) non-optical – based on pressure, capacitance or temperature sensor



(d) “sweep” sensor

Figure 11. Fingerprint sensors

In Figure 11 various technologies for fingerprint sensing are shown [31]. The most popular approach (see Figure 11 (a)) is based on optical sensing and light reflection from the finger surface. Also, this type provides high robustness to finger condition (dry or wet), but the system itself is tend to be bulky and costly. Alternative solutions that can provide compact and lower cost solutions, are based mostly on solid state sensors where the finger is directly placed on the sensor. However, in these solutions the sensor size needs to be at least equal to the size of the finger part used for sensing. Two sensors of this type are shown in Figure 11 (b) and (c). The first one is based on light transmitted through the finger and then sensed by the image sensor, while the second one is the non-optical sensor that can be implemented either as pressure, capacitance or temperature sensor. The fingerprint sensor, known as a “sweep” sensor and shown in Figure 11 (d), can be implemented using either the optical or other previously mentioned techniques. A “sweep” sensor employs only a few rows of pixels, thus in order to get a complete fingerprint stamp the finger needs to be moved over the sensing part. Such technology greatly reduces the cost of the sensor due to reduced sensor area and solves the problem of fingerprint stamp that needs to be left on the surface in the first two methods.

In all presented methods, the output signal is usually an image and the sensors are composed of pixels that sense either temperature, pressure, photons or change in capacitance. The overall architectures of these sensors are similar to the architecture described in section II and they integrate various image and signal processing algorithms, implemented the same die. Various research papers have been published in this area and numerous companies are working on such integration. For example, in [32] the authors implement image enhancement and robust sensing for various finger conditions. Capacitive sensing CMOS technology is used and data is processed in a column parallel way. The same technology is used also in [34], but the fingerprint identifier is also integrated and the data is processed massively in parallel for all pixels.

Despite the fact that fingerprint technology is quite mature, there is much work to be done to reduce power consumption, to improve technology and image processing algorithms and to achieve better system miniaturization.

4. Image Sensors in Medical Applications

Almost all medical and near medical areas benefit from image sensors utilization. These sensors are used for patients' observation and drug production, inside the dentists offices and during surgeries. In most cases the sensor itself represents only a small fraction (in size and cost) of the larger system, but its functionality plays a major role in the whole system. Figure 12 shows examples of medical applications where CMOS image sensors are used. In this section of the paper we mostly concentrate on applications that push current image sensor technology to the edge of the possibilities. These applications are wireless capsule endoscopy and retinal implants. Both of these applications will play an important role in millions of patients' lives in the near future.

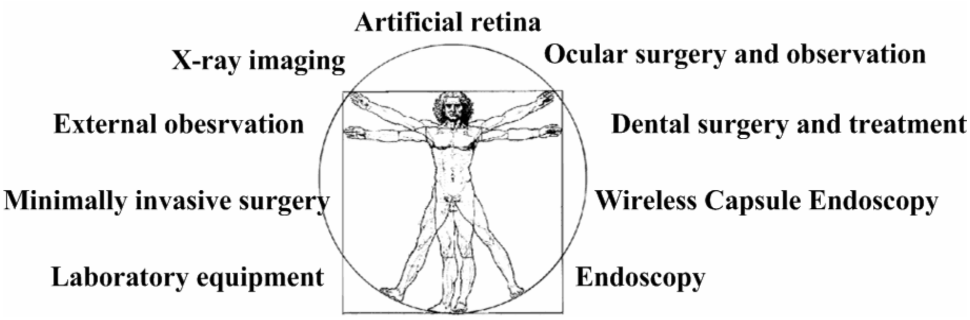


Figure 12. Image sensors applications in medicine

4.1 Wireless Capsule Endoscopy

Conventional medical instrumentation for gastrointestinal tract observation and surgery uses an endoscope that is externally penetrated. These systems are well developed and provide a good solution for inter-body observation and surgery. However, the small intestine (bowel) was almost not reachable using this conventional equipment, leaving it for observation only through surgery or through an inconvenient and sometimes painful push endoscopy procedures. Few years ago the sphere was revolutionized by the invention of the wireless image sensor capsule, which after swallowing, constantly transmits a video signal during its travel inside the body [1]. The capsule movement is insured by the natural peristalsis. According to Gavriel Iddan [1], the founder of Given Imaging™ [35] that commercializes this technology, "The design of the video capsule was made possible by progress in the performance of three technologies: complementary metal oxide silicon (CMOS) image sensors, application-specific integrated circuit (ASIC) devices, and white-light emitting diode (LED) illumination".

The general architecture of the capsule is shown in the Figure 13. It consists of LEDs, optics, camera, digital system processing, transmitter or transceiver and a power source. The dashed blocks represent additional future requirements for such capsules.

All capsule electronic components are required to be low power consumers to enable constant video transmission for a prolonged time (for about 6-8 hours) and/or high capacity batteries. An alternative solution to in-capsule batteries [36] is to use an external wireless power source that supplies energy to the capsule through electromagnetic coils. Such a solution enables to relax power requirements for the capsule electronics. This solution also provides an advantage in freeing space inside the capsule for other useful functions such as biopsy or medication. Also, the capsule position can be controlled externally through a strong magnetic field. But the required strong magnetic field can limit the capsule usage in spite of position control advantages [33].

Currently the Given Imaging™ capsule developers have reached very encouraging results enabling two capsules: one intended for the Esophagus part (the upper part) of the gastrointestinal tract and the second for small intestine observation. The first kind of the capsule is equipped with two CMOS image sensors and can transmit the video signal for about 20 minutes with 14 frames per second for each camera. The second one consists of only one CMOS image sensor and can transmit two frames per second for about eight hours. The company is developing now a new capsule generation that can transmit four frames per second.

Despite these encouraging results, a lot of work should be done to allow further miniaturization, image processing and compression algorithms integration, power reduction by various means (system integration, technology scaling etc.), frame-rate increase, quality improvement and usage of alternative power sources with larger capacity. The ultimate goal that needs to be achieved is full video frame-rate transmission for about 7-8 hours. To achieve these goals, a number of additional research groups work worldwide on wireless capsules development: eStool by Calgary university in Canada [37], MiRO by Intelligent Microsystems Center in Korea [38], EndoPill by Olympus [39].

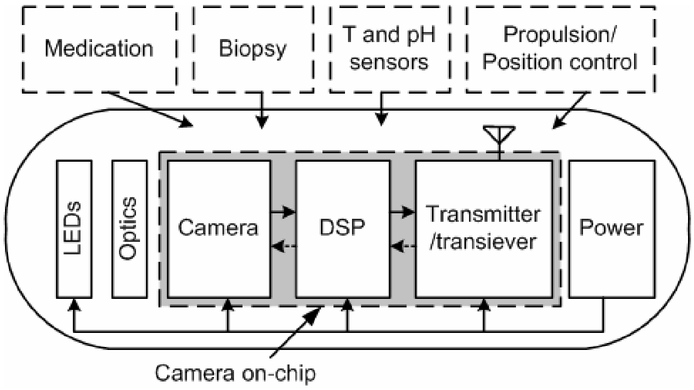
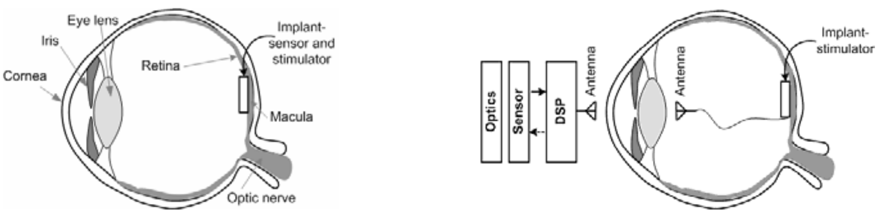


Figure 13. The swalable capsule architecture.
In the dashed boxes additional functionality that will be required in the future is shown

4.2 Artificial Retina

Artificial vision is another example of CMOS image sensors implementation in medical applications. Today millions of people are suffering from full or partial blindness that was caused by various retinal deceases. In the early eighties it was shown that electrical stimulation of the retinal nerves can simulate visual sensation even in the patients with fully degraded receptors. Recently, researchers in a number of research institutes have developed miniature devices that can be implanted into the eye and stimulate the remaining retinal neural cells, returning partial vision ability for the blind patients. Such implants are called artificial retinas. Usually they are implanted in the macula area that normally is densely populated by the receptors and enables high-resolution vision. This break-through was enabled by the progress in electronics, surgical instrumentation, and biocompatible materials. Currently there are two major approaches for artificial retina development (see Figure 14).



(a) (b)

Figure 14. Artificial retinas: (a) implantable sensor (b) external sensor

The first and the most promising one is the integration of sensing and stimulation elements in the same device and the second is separation of sensing and stimulation. In the first approach, an artificial retina device is an autonomous circuitry that does not require external control and the optics that is used for sensing is the natural optics of the eye composed of the cornea and lens. In the second, all the sensing and processing is performed outside of the eye and only stimulating elements are implanted during surgery. The data transfer from the sensing part to the stimulation part is performed through an RF link or through a tiny cable. In both approaches the implant can be subretinal or epiretinal.

Actually there is a number of groups working in the field [40]-[44] but we will concentrate on two that have shown very promising results and are now performing clinical trials and commercialization through companies named Optobionics™ [40] and Second Sight [41]. Both groups already have a number of patients with such implants.

The device developed by Optobionics™ group does not require any power source, integrates about 5000 sensing (microphotodiodes) and stimulation (electrodes) elements, features two millimetres in diameter and is implanted under retina. The basic artificial silicon retina unit is shown in Figure 15 [45]. It is composed of a stimulating electrode and three PIN photodiodes connected in series to increase the output voltage.

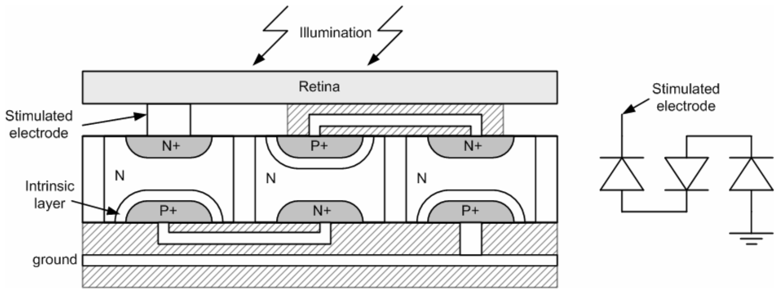


Figure 15. Artificial silicon retina – basic unit

The second group decided to follow the second approach and separate sensing from stimulation. The camera with the processor is situated on the patient glasses and the signal is transmitted through a cable to the eye that has an implanted stimulator. Currently, the implant resolution is not so impressive compared to the first group and features only 16 electrodes, but the developers plan to increase the resolution in the future models to 60 and 1000 electrodes [46].

5. Conclusions

In this paper we have presented a brief review of CMOS image sensors utilization in security and medical applications. In these applications image sensors play a major role and usually define the edge of the imaging technology. Despite the CMOS image sensor technology already exists for more than a decade, it is continuously developing and penetrating into new fields that were unreachable by its predecessor, CCD technology. Although many successes have been achieved during the last decade, a lot of work still needs to be done in this area. It requires extensive collaboration between various fields such as: electrical engineering, materials, computer science, medicine, psychology, chemistry etc. As to the electrical engineering and sensing fields, the work should be concentrated in the directions of power consumption reduction, functionality improvement and system integration. However, like in every multidisciplinary, electrical engineers, developing the electronic devices for medical purposes, are required to understand all above mentioned fields to successfully implement such devices.

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MANOMETRY-BASED COUGH IDENTIFICATION ALGORITHM

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***Abstract**: Gastroesophageal reflux disease (GERD) is a common cause of chronic cough. For the diagnosis and treatment of GERD, it is desirable to quantify the temporal correlation between cough and reflux events. Cough episodes can be identified on esophageal manometric recordings as short-duration, rapid pressure rises. The present study aims at facilitating the detection of coughs by proposing an algorithm for the classification of cough events using manometric recordings. The algorithm detects cough episodes based on digital filtering, slope and amplitude analysis, and duration of the event. The algorithm has been tested on in vivo data acquired using a single-channel intra-esophageal manometric probe that comprises a miniature white-light interferometric fiber optic pressure sensor. Experimental results demonstrate the feasibility of using the proposed algorithm for identifying cough episodes based on real-time recordings using a single channel pressure catheter. The presented work can be integrated with commercial reflux pH/impedance probes to facilitate simultaneous 24-hour ambulatory monitoring of cough and reflux events, with the ultimate goal of quantifying the temporal correlation between the two types of events.*

***Keywords**: Biomedical signal processing, cough detection, gastroesophageal reflux disease.*

***ACM Classification Keywords**: I.5.4 Pattern Recognition: Applications – Signal processing; J.3 Life and Medical Sciences*