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*VLSI Laser Spot Sensors for 3D Digitization **

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September 2001

* published in Proceedings of the Third Topical Meeting on Optoelectronic Distance / Displacement Measurements and Applications (ODIMAP III), Pavia, Italy. September 20-22, 2001. pp. 208-213. NRC 44884.

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VLSI Laser Spot Sensors for 3D Digitization

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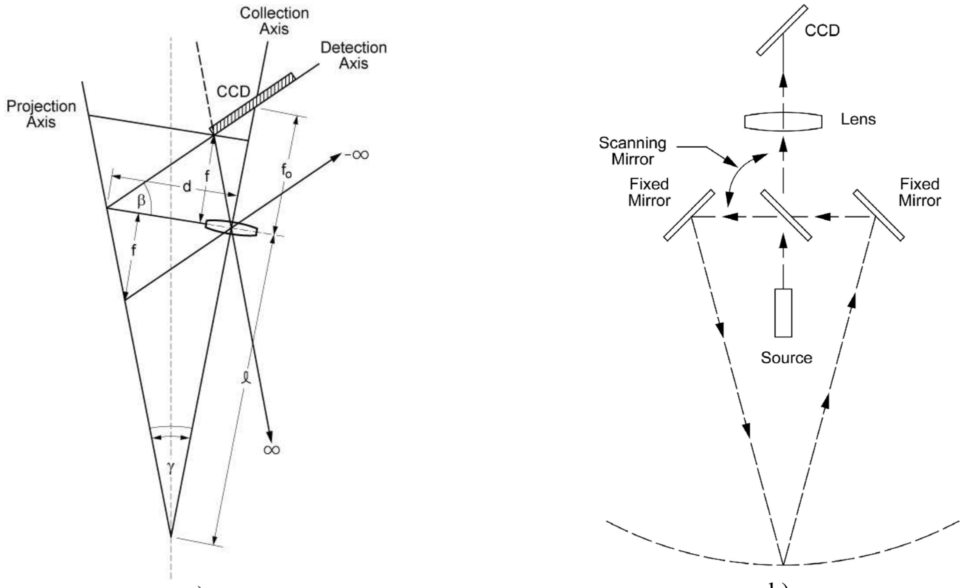
Abstract – This paper presents activities on VLSI laser spot sensors for digital 3D imaging developed for industrial and scientific applications. All the sensors have been fabricated using standard CMOS technology that allows the monolithic integration of photo-sensors, together with readout circuits, and digital signal processors. Preliminary results are presented.

1 INTRODUCTION

High-resolution 3D images can be acquired using laser-based vision systems. With this approach, the 3D information becomes relatively insensitive to background illumination and surface texture. Complete images of visible surfaces that are rather featureless to the human eye or a video camera can be generated. Figure 1a depicts the classical optical geometry for triangulation. Two digital 3D imaging systems were developed and demonstrated at the NRC. They are the auto-synchronized scanner [1] and the BIRIS [2] system. The auto-synchronized scanner, depicted schematically on Figure 1b, can provide registered range and colour data of visible surfaces. A 3D surface map is captured by scanning a laser spot onto a scene, collecting the reflected laser light, and finally focusing the beam onto a linear laser spot sensor. Geometric and photometric corrections of the raw data give two images in perfect registration: one with *x, y, z* co-ordinates and a second with reflectance data. The laser beam composed of multiple visible wavelengths is used for the purpose of measuring the colour map of a scene (reflectance map). Digital 3D imaging can benefit from advances in VLSI technology in order to accelerate its deployment in many fields like visual communication and industrial automation. The NRC and ITC groups are collaborating on a project that is targeted at the integration of key sensors used in the auto-synchronized scanner. These sensors include the synchronization photodiodes based on bi-cells [3] and laser spot position measurement sensors – know as Colorange [4]. These sensors could become an integral part of future intelligent digitizers that will be capable of measuring accurately and simultaneously colour (reflectance) and 3D. This, in turns, will accelerate the development of hand-held 3D cameras [5] and multi-resolution random access laser scanners for fast search and tracking of 3D features [4]. All these digitizers will require a thorough VLSI integration of basic laser camera functions to achieve size and cost reduction and most importantly, higher performance.

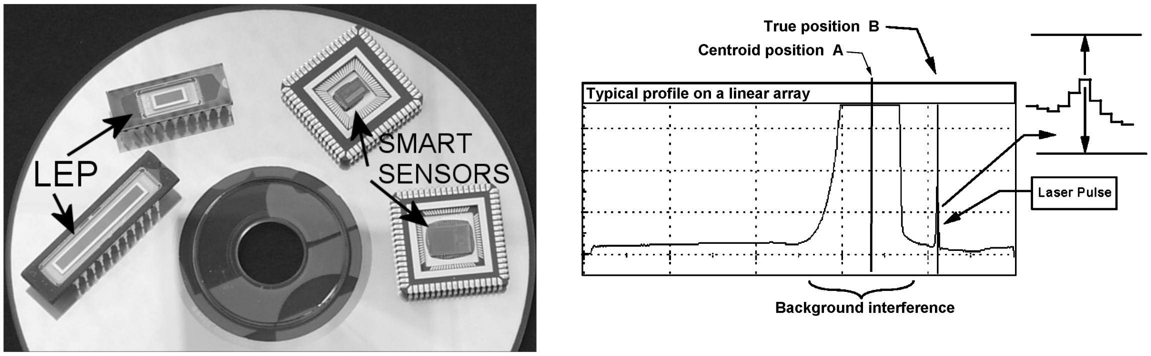


a) b)

Figure 1 Optical triangulation a) classical optical geometry for triangulation b) auto-synchronized scanner with single scan axis.

2 PROPOSED SENSOR - COLORANGE

Currently, commercial photodiode arrays used in 3D vision sensors are intended for 2D imaging applications, spectroscopic instruments or wavelength division multiplexing in tele-communication systems. Their specifications change according to the evolution of their respective fields and not to digital 3D imaging. For instance, speckle noise dictates a large pixel size [6] that is not compatible with current 2D imaging developments (where pixels are getting smaller). Many devices have been built or considered in the past for measuring the position of a laser spot more efficiently. Among those, one finds continuous response position sensitive detectors (CRPSD) and discrete response position sensitive detectors (DRPSD) [7-8]. The category CRPSD includes lateral effect photodiode (see Figure 2a) and geometrically shaped photo-diodes (wedges or segmented). A CRPSD provides the centroid of the light distribution with a very fast response time (in the order of 10 Mhz). DRPSD on the other hand comprise detectors such as Charge Coupled Devices (CCD) and arrays of photodiodes equipped with a multiplexer for sequential reading. They are slower because all the photo-detectors have to be read sequentially prior to the measurement of the location of the peak of the light distribution [4]. Furthermore, consider the situation depicted on Figure 2b, a CRPSD would provide **A** as an answer. But a DRPSD can provide **B**, the desired response. This situation occurs frequently in real applications. The elimination of all stray light in an optical system requires sophisticated techniques that increase the cost of a system. Also, in some applications, background illumination cannot be completely eliminated even with optical light filters.



a) b)

Figure 2 Position sensors: a) photographs of some lateral effect photodiodes (LEP or CRPSD) and some smarts sensors designed by IRST/NRC, b) typical situation where stray light blurs the measurement of the real but much narrower peak. A **CRPSD** would provide *A* as an answer and a **DRPSD** *B*, the desired response peak.

We propose to use the best of both worlds. Theory predicts that a CRPSD provides very precise measurement of the centroid versus a DRPSD [4]. By precision, we mean *measurement uncertainty*. It depends among other things on the signal to noise ratio and the quantization noise. In practice, precision is important but accuracy is even more important. A CRPSD is in fact a good estimator of the central location of a light distribution. On the other hand, DRPSDs are very accurate because of the knowledge of the distribution but slow. Obviously, not all photo-sensors contribute to the computation of the peak. In fact, what is required for the measurement of the light distribution peak is only a small portion of the total array. Hence the new smart detector. Once the pertinent light distribution (after windowing around an estimate around the peak) is available, one can compute the location of the desired peak very accurately.

Figure 3 shows schematically the new smart position sensor for light spot measurement in the context of 3D and colour measurement. In a monochrome range camera, a portion of the reflected radiation upon entering the system is split into two beams (Figure 3a). One portion is directed to a CRPSD that determines the location of the best window and sends that information to the DRPSD. In order to measure colour information, a different optical element is used to split the returned beam into four components, e.g., a diffractive optical element (Figure 3b). The white *zero order* component is directed to the DRPSD, while the RGB 1st order components are directed onto three CRPSD which are used for colour detection (Figure 3c). The CRPSDs are also used to find the centroid of the light distribution impinging on them and to estimate the total light intensity. The centroid is computed on chip for each colour with the well-known current ratio method i.e. (I1-I2)/(I1+I2) where I1 and I2 are the currents generated by that type of sensor [4]. The weighed centroid value is fed to a control unit that will select a sub-set (window) of contiguous photo-detectors on the DRPSD. That sub-set is located around the estimate of the centroid supplied by the CRPSD. Then, the best algorithms for peak extraction can be applied to the portion of interest.

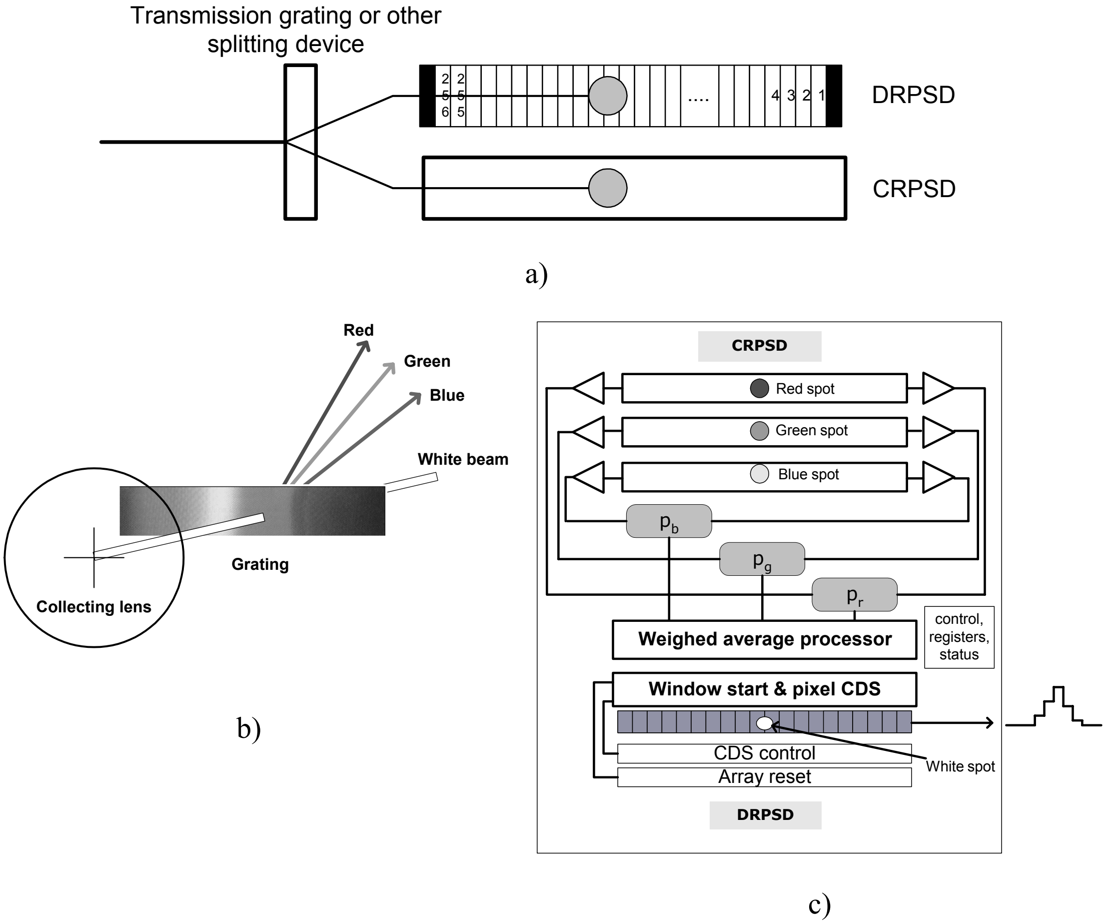
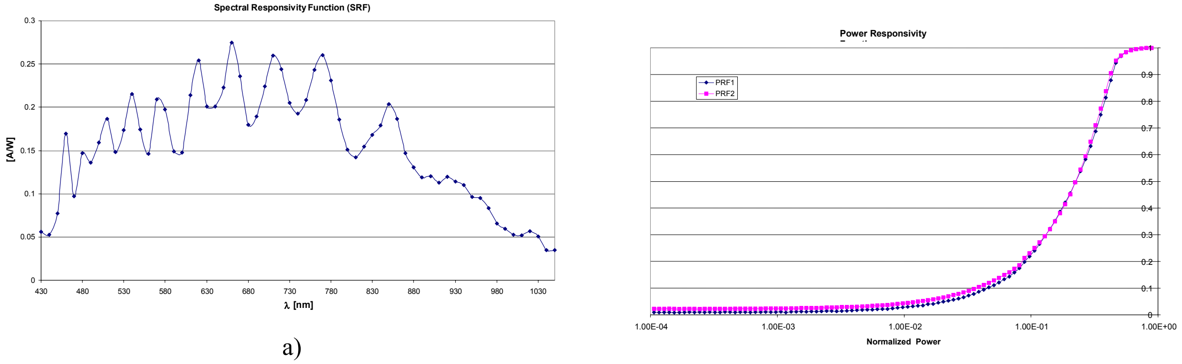


Figure 3 Description of the smart sensor for laser spot detection: a) in a monochrome system, the incoming beam is split into two components, b) artistic view of a smart sensor with colour capabilities, and c) the proposed architecture for the Colorange chip.

3 IMPLEMENTATION AND EXPERIMENTAL RESULTS

We present here the architecture and preliminary experimental results of a first prototype chip of a DRPSD with selectable readout window. This is the first block of a more complex chip that will include all the components illustrated in Figure 3c. The prototype chip consists of an array of 32 pixels with related readout channels and has been fabricated using a 0.8µm commercial CMOS process. The novelties implemented consist in a variable gain of the readout channels and a selectable readout window of 16 contiguous pixels. Both features are necessary to comply with the requirements of 3D single laser spot sensors, i.e., a linear dynamic range of at least 12 bits and a high 3D data throughput. In the prototype, many of the signals, which, in the final system are supposed to be generated by the CRPSDs, are now generated by means of external circuitry. The array pitch is 50µm with each pixel having a sensitive area of 48 x 500 μm^2. The large dimensions of the pixel are required, on one side to cope with speckle noise [6] and, on the other side, to facilitate system alignment. Each pixel is provided with its own readout channel for parallel reading. The channel contains a charge amplifier and a correlated double sampling circuit (CDS). To span 12 bits of dynamic range, the integrating capacitor can assume five different values. In the prototype chip, the proper integrating capacitor value is externally selected. In the final sensor, however, the proper value will be automatically set by an on chip circuitry on the basis of the total light intensity as calculated by the CRPSDs. During normal operation, all 32 pixels are first reset at their bias value and then left to integrate the light for a period of 10µs. Within this time the CRPSDs and an external processing unit estimate both the spot position and its total intensity and those parameters are fed to the window selection logic. After that, 16 contiguous pixels, as addressed by the window selection logic, are read out in 52µs, for a total frame rate of 64µs. Future sensors will operate at full speed, i.e. an order of magnitude faster. The chip has been tested and its functionality proven to be in agreement with specifications. The experimental results relative to spectral responsivity and power responsivity are illustrated on Figure 4a and b respectively.



a)

b)

Figure 4 a) Spectral responsivity and b) Normalized power responsivity for two samples.

The spectral responsivity has a maximum value of ~0.25 A/W and is found at around λ~660nm. The several peaks in the curve are due to multiple reflection of light passing through the oxide layers on top of the photosensitive area. The power responsivity has been measured by illuminating the whole array with a white light source and by measuring the pixel response as the light power is increased. As expected, the curve (Figure 4b) can be divided into three main regions: a far left region dominated by photoelement noise, a central region where the response is linear with the impinging power and a saturation region. The values of the slope, linearity and dynamic range of the central region have been calculated for three chips and are 0.167 A/W, 2.9% and 47 dB respectively.

4 CONCLUSIONS

The results obtained so far have shown that optical sensors have reached a high level of development and reliability that are suited for high accuracy 3D vision systems. The availability of standard fabrication technologies and the acquired know-how in the design techniques, allow the implementation of optical sensors that are application specific: Opto-ASICs. The trend shows that the use of the low cost CMOS technology leads competitive optical sensors. Furthermore post-processing modules, as for example anti reflecting coating film deposition and RGB filter deposition to enhance sensitivity and for colour sensing, are at the final certification stage and will soon be available in standard fabrication technologies. The work on the Colorange is being finalized and work has started on a new improved architecture.

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