Hardware environment for a retinal CCD visual sensor

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Abstract

A CCD retinal sensor has been developed recently. The main property of this device is to perform the log-polar transform in real time due to its specific pixel disposition.

This device differs in structure respect to the matrix based CCD sensors used in normal cameras. This special structure requires a specific hardware to deal with the generated signals and the control of the device.

In this article we describe the work environment of this sensor. There are basically three parts, that has been developed for this special chip. The first one is the sensor itself, the second one is the module to generate the different signal that the sensor needs to work properly. The last one is a special frame grabber that stores the images to be processed in a host computer.

1 Introduction

Information organization plays an important role in environment image perception. One of these organization of the information is the space-variant representation, that has interesting organization properties [1]: image data are reduced in a selective way, maintaining accurate resolution in the foveal area but globally minimizing the amount of information needed to describe the image.

Only recently, however, with the realization of the CCD retinal sensor, are vision techniques based on space-variant sensing becoming feasible for practical applications [2, 3, 4]. The CCD sensor speeds up the image processing, performing a log-polar transformation in real time, on the chip itself, in the very instant of the acquisition.

This chip is a reality now, nevertheless, it is rather different from its predecessors, the CCD camera sensors, that have achieved their current performance after more than 20 years of research. The current CCD retinal sensor takes advantage of this CCD previous research, but due to its special structure, new CCD design con-

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cepts have to be introduced.

To deal with this concept of space variant vision, a special chip [5] has been designed, as well as all the necessary control electronics.

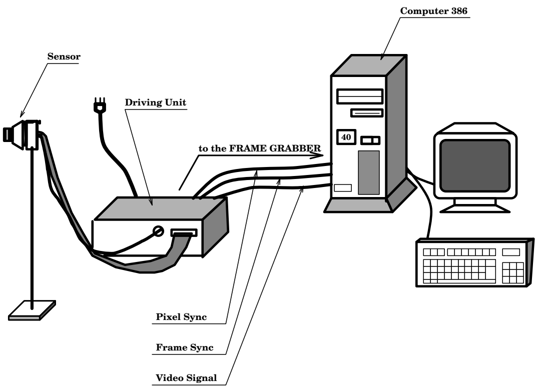

Figure 1: Hardware environment for the retinal sensor.

The retinal work environment set up consists of four basic elements [6]. The first one is, of course, the chip itself. The next element of the development system is the driving unit that generates the signals (almost 30) to drive the chip, and provides, to the next element in the chain, the video information. The third element is a frame grabber specially designed to deal with the non-standard video signal provided by the driving unit. This frame grabber should also be able to normalize and store the image. The last element is a host computer where high level image processing operations can be performed to the image. It is possible to see a complete set up of the system in figure 1.

2 CCD retinal chip

The structure of the sensor is organized by circumferences [7]. The radius of these circumferences (a total of 30), decrease following a logarithmic function, obtaining in this way, a log-polar representation of the image. Each circumference is divided in 64 pixels, and all of them have the same number of pixels. The structure of the sensor is represented in the figure 2. The internal part of the structure differs from the periphery. This part corresponds to the "fovea" in the human eye, and it is the part with higher resolution. It is not possible to fill this area following the same structure, because the pixels would have to be smaller and smaller and there is a technological size constraint. The solution adopted was to fill this area with a homogeneous squared CCD array.

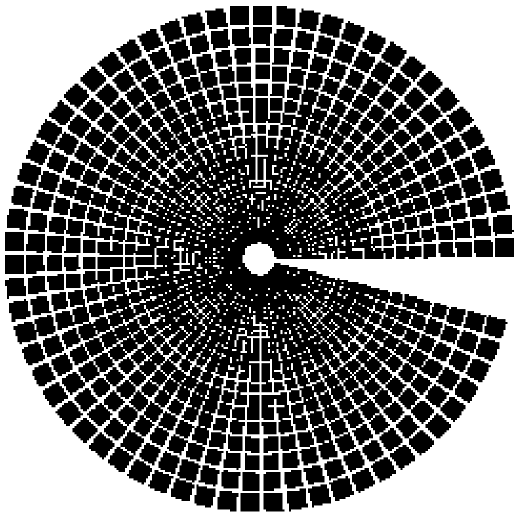

Figure 2: Structure of the CCD retinal sensor.

The first problem of this structure is the different size of the pixels. In the inner part, the pixels are very small, while in the outer part the pixels are really big. Different sizes of CCD pixels mean different light responses. The first step was to make the size homogeneous. To do so, the sensor was divided in three parts. The inner part contains the first 10 circumferences, and each pixel is composed by one photosite or CCD cell. The middle part, another 10 circumferences, has the peculiarity that each pixel has two CCD photosites. The outer part, the last 10 rows, has all the pixels divided in 4 CCD photosites. In this way, the number of pixels in each circumference is the same, while the number of CCD cells differs for each circumference.

It is evident that all the pixels still have a different size, and then, the same light generates different charges depending on the size. To normalize these differencies a charge divider is provided for each circumference. This charge divider, or coupler, divides the charge attending to the size of the pixels and it is different for each circumference.

The last step is to take out the charges from the pixels. For a proper transport of the charges through the CCD cells, it is necessary that they move through cells of the same size. It means that it is not possible to read out the charges moving them from one circumference to another. The only possibility is to move them through the same circumference to the coupler, and pass the charge from the coupler to a "radial" CCD that goes from the center of the sensor to the periphery. Therefore, it is needed a space within the sensor area to put this radial CCD and the coupler. This is why it is possible to see in the layout (figure 2) a blind zone in one of the sides.

Attending to these considerations, a CCD chip was designed within a collaborative project involving European and United States research laboratories [1]. The final result chip is shown in the figure 3.

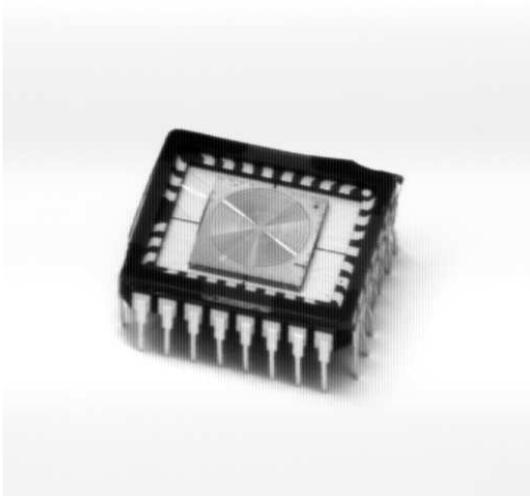

Figure 3: CDD retinal visual sensor.

3 Driving unit

There are many signals needed to control the sensor chip. The charge transfer is based on three out of phase signals. It means that only three signals are needed to transfer charges from one CCD cell to the next [8]. The problem in this sensor is that there are different kinds of CCD cells and, therefore, three signals have to be provided to each type of CCD cell. There are four groups of CCDs that requires different synchronization. Three groups are the three different areas in which the sensor was divided. The different synchronization between them is due to the different number of CCD cells in each group. In the outer part there were 4 CCD cells for each pixel, while in the medium part there were 2 and in the inner part there were only one. As long as the pixels are readout at the same time, the clock signal frequency of the outer part is double than the medium part, and this one double than the inner part, because, 4, 2 and 1 charged cells respectively have to be readout at the same time. The last group is the radial CCD, that has its particular three clocks because, while the circular CCDs move one charge, the radial CCD moves 165.

Four different groups and three signals for each one makes a total of 12 different signals only to transfer the charges through the CCD cells. But there are more. The coupler had the function of

[1] The design of the sensor involved Dept. of Computer Science - University of Genoa, Dept. of Electrical Engineering - University of Pennsylvania, Scuola Superiore S. Anna of Pisa and IMEC in Leuven, Belgium; the fabrication of the chip is done at IMEC.

splitting the charge to normalize it. Four more signals are needed in order to perform this function. This signals expand the charge in a single CCD, that is then split in two. Only one side is valid and transferred to the radial CCD.

Two more signals have to be provided at each row and at each frame for reset purposes. It makes a total of 18 signals. Different CCD cell sizes also mean different driving voltages, therefore, this 18 signals have to be driven high or low with the proper voltage that is usually different for each group of signals.

Along with these signals there are other dedicated to power supply of the different elements of the CCD sensor. As long as there some different elements inside the chip, more than one continuous voltage has to be provided.

The signals described controls the sensor chip. The driving unit must also provide the video signal to the frame grabber. One part of the driving unit is dedicated to amplify the video signal from the sensor. Along with this analogic video signal, the pixel and frame synchronisms have to be provided to the frame grabber. The pixel synchronism signal indicates, to the A/D of the frame grabber, when to sample and hold the video signal to be converted. The frame synchronism signals the end or begin of a frame.

There are some implementations of driving units [9, 10]. The difference are basically the module that generates the clock signals. There is actually a chip that generates all these signals. It has been made at the University of Pennsylvania using CMOS technology [11]. Other implementation of the driving unit has been made at the University of Pisa, where an EPROM with some registers implemented the state machine that generates the signals. The problem with this last implementation is basically the space. Now, a new chip has been made at the University of Genova (DIST). This chip have been made from only one EPLD. The advantages of this new release of this chip is that it is cheaper than any semicustom CMOS VLSI design, it is more flexible, for the chip can be erased and reprogrammed. The specification of the chip has been made using a high level hardware description language that it is easy to change, to adapt to new versions, and to port to other ASIC technologies (FPGAs, CMOS, Gate Arrays...).

The research on the driving unit is currently focused on the reduction of its size. The retinal sensor is specially suited for active systems, that usually requires the movement of the cameras[12]. It means that the cameras to be mounted in the mobile parts of the robot should be as smaller as possible to avoid inertial and mechanical control problems. The chip described in the last paragraph is a step beyond the reduction of the driving electronics of the retinal camera.

4 Frame grabber

The frame grabber takes the video signal and the synchronism signals, from the driving unit, and generates the image.

The structure of this frame grabber is very similar to the frame grabbers used for normal cameras in robotics. The difference is basically the input that doesn't follow any standard. The video signal is basically an analogic signal containing the voltage corresponding to each pixel. The frame grabber takes this analogic signal and samples it with the pixel synchronism signal. Once the signal is sampled is converted to digital through the A/D converter. This digital value is then stored in a memory.

There are, in the retinal sensor, CCD cells of different sizes. As commented before, these different sizes generate different responses for the same light intensity. This problem is partially solved with the coupler, that makes a charge division, but it is not enough and it is necessary to normalize the image again using a more accurated method.

So far, this normalization was performed by the host computer. There was a table in the memory with a scale value for each pixel, when the image is acquired, each pixel value is multiplied by this factor and, therefore, rescaled. The retina sensor is specially good for real time systems [13], but from the real time processing point of view, this is not a good method. All the time between two images should be used to process the image and not to rescale it. The other solution is to make this normalization process in the frame grabber, so when the host computer wants to process the image, it has been already normalized.

A frame grabber has been developed in the University of Genova [14]. This frame grabber has some differences respect to its predecessors. First of all, there is a module inside the board dedicated to the hardware normalization of the image. This module is basically a Look Up table with the necessary information to scale the value of each pixel. This operation takes place in real time, when a new pixel arrives, the last one has been already processed and stored. Other differences are the size and flexibility. Though this frame grabber has more functions, the size is rather small[2]. A register architecture have been also implemented inside the board to avoid the internal hardware manipulation (the number of switches has been reduced to the minimum, and all the functions can be programmed from the host computer). All these improvements have been achieved through the use of programmable devices (EPLDs in this case).

[2] About 1/3 of the existing frame grabbers for the retina sensor.

5 Conclusion

The hardware environment of the retinal sensor development system have been described. The research on the implementation of space variant CCD has a history of very few years. Nevertheless, it has been possible to provide a system that acquires images with acceptable quality.

Many problems are still unresolved, and basically concern to the retina chip and the CCD technology. CCD is a very good technology for implementing arrays of pixels and so on, its quality and performance are better than any other technology. Out of these simple array structures, many problems arise. In the retina chip it is possible to see a blind area within the chip, and this problem is difficult to avoid. Charges has to be taken out from the photosites, and it has to be done through CCD cells. Between the photosites and this radial CCD there is also a coupler, for the scaling of the charges due to the different sizes of the CCDs. All this components need a space in the photosensible area creating this blind zone.

Other problems refer to the fovea. Currently it is a squared array of pixels in the middle of the sensor. It seems to work, but from the image processing point of view, this structure is not the best. Processing pixels in the space variant area is good, as well as in the fovea, the problems arise for the pixels around the boundaries between the fovea and the space variant area. It is almost impossible to calculate the neighbors of a pixel when it is between these two areas. A new structure for the fovea should be implemented, although it is really complicated due to the constraints of the CCD technology.

In the other hand, the driving unit has to provide almost 30 signals to the CCD chip. It means a big and heavy driving unit. If we take into account that most of the applications of this camera require it to be mounted in a mobile head, a heavy driving unit is not anymore a good idea.

CMOS technology is starting to take a place in the cheap visual sensors arena [15]. The quality and performance of these sensor are still worst than the CCD cameras, though they are improving each year [16, 17]. The advantages of this technology is the price, the availability, and specially, the design flexibility. This last characteristic is exactly what a space variant sensor needs, due to its strange structure. Further research will be carried out in this field with some practical result in one or two years.

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