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Very High Speed Multi Resolution Sheet-of-light Range Imaging

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Abstract

Sheet-of-light range measurement is a commonly used method in todays industrial applications. This paper describes a new way of using an existing image sensor and turns it into a fast programmable sheet-of-light range sensor. The system is capable of measuring up to 4 Mrangle/s.

1 Introduction

Sheet-of-light, SOL, range imaging is a well known technique where the distance to each point along a line in a scene is measured. The camera and the line projector are spatially separated, see Figure 1, which means that the impact of the line on each column of the two dimensional sensor is a measurement of the distance to that point in the scene.

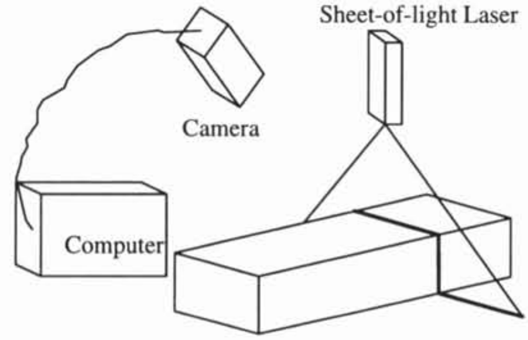

Figure 1, Sheet-of-light, SOL, range system

Fast and accurate range measurements are very important in industrial applications. In many applications there are needs to adjust resolution and speed. For instance, when the inspection speed is low we want to have high accuracy. However, when the speed increases the relative accuracy might be reduced. Sometimes there is also a demand to have different spatial resolution along the line to increase the speed.

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A number of specialized sensor architectures have been presented in the literature, e.g. [3] and [4]. In this paper we will describe a SOL range system based on a sensor which has not been targeted to this application. The sensor is called CIVIS [5] and has been designed for multi resolution imaging. In our system we have used this feature both to implement the SOL algorithms and to have possibility to decrease the spatial resolution to gain speed and precision.

The CIVIS sensor is a 2D sensor with a resolution of 256x256. Figure 2 shows the design of the sensor. Each column of photodiodes has its own readout unit (a). This unit is used both for the readout and the initialization of the photodiodes. For each column, an analog summation of a number of photodiodes can be performed by addressing these rows without resetting the readout unit in between. The rows can be addressed in an arbitrary order and the integration time of each row, which is the time between two successive readouts, can also be choosen arbitrarily. The chip has one common readout circuit (b) which is connected to all column readout units. Here, we can again address the column in arbitrary order and we can also perform horizontal analog summations.

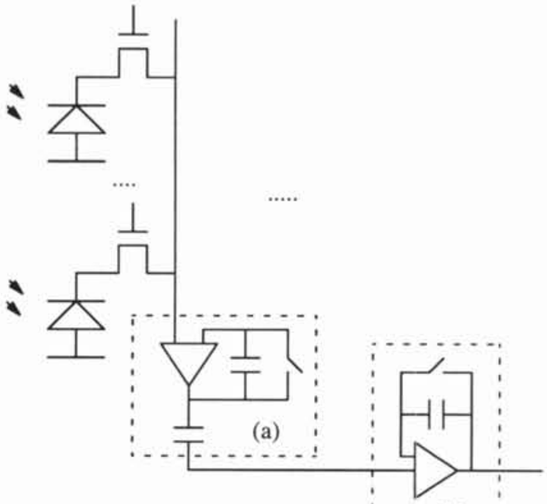


Figure 2, The CIVIS sensor

The basis in our sheet-of-light range system is the very fast algorithm called the Forward Backwards Method, FBM [1][2]. The object is to find the center of gravity of the laser line for each column. A vertical cross section of the image can look like Figure 3.

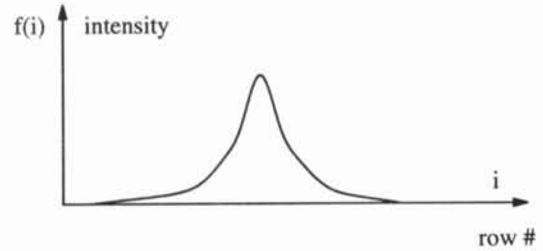


Figure 3, Cross section of the laser line

In FBM we perform two analog summations of a number of consecutive rows. First we sum the content of rows n_1 to n_2 and A/D-convert it. This is done at time t_1 in Figure 4. This sum is called $S_F(x)$, where x is the column. We then perform a new summation, $S_B(x)$, from row n_2 to row n_1 and ADC it at time t_2 in Figure 4. Since this readout pattern is repeated them two sums can be described as

$$S_F(x) = \sum_i i \cdot f(x, i) \qquad (1)$$

$$S_B(x) = \sum_i (N - i) \cdot f(x, i) \qquad (2)$$

given an image f(x,i).

The sum of the two sums corresponds to the grey scale value of the line

$$S(x) = S_F(x) + S_B(x) = N \sum_i f(x, i) \qquad (3)$$

We can then compute the center of gravity at each position along the line using the following formula

$$C(x) = \frac{S_F(x)}{S_F(x) + S_B(x)} = \frac{\sum_i i \cdot f(x, i)}{N \sum_i f(x, i)} \qquad (4)$$

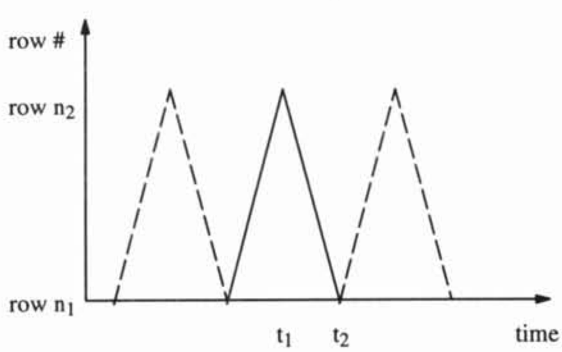


Figure 4, Ideal readout pattern

2 Implementation

The implementation of FBM on the CIVIS chip is done by first addressing a number of rows in one direction. The analog sums of all columns will now be at the readout circuit at each row. The data are then read out from the chip one by one through the horizontal readout circuit common to all columns. After that, a new addressing and readout of the same rows, in the opposite order, takes place. These sums are once again read out from the chip using the horizontal readout unit. We now have the two sums and the operations to calculate S and C can take place digitally outside the chip.

We must also consider that the readout pattern can not be as ideal as shown in Figure 4. We must take into account that we have to perform the readout and the A/D-conversions after each scan as shown in Figure 5. During this time the laser line will be turned off.

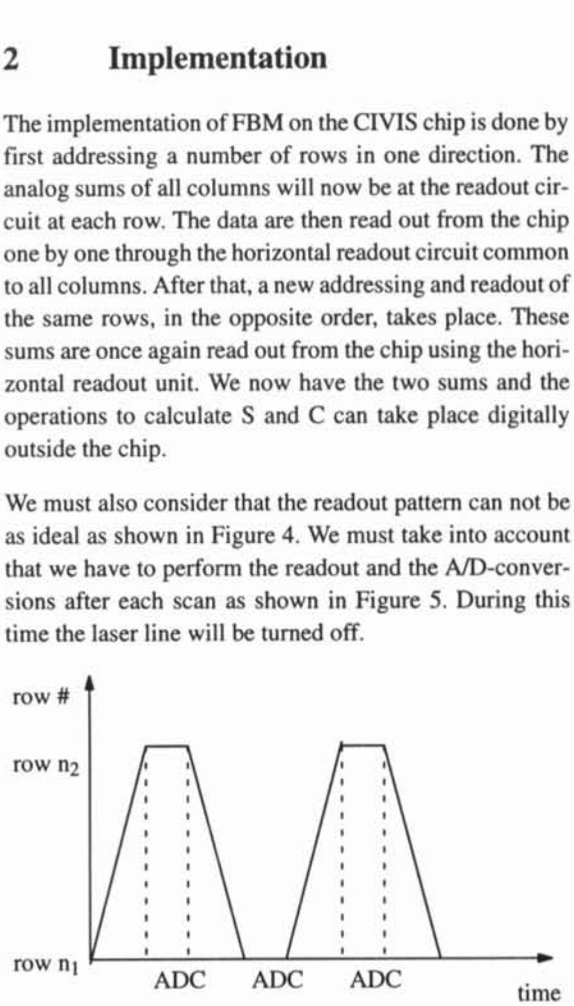


Figure 5, Modified readout pattern

The performance of the system in the CIVIS implementation is dependent on a number of parameters.

$$T = 2Nt_1 + 2t_2 + 2M_0t_0 + 2M_1t_0 \qquad (5)$$

$t_0 = 0.05\mu s$: *Horizontal readout time*

$t_1 = 0.4\mu s$: *Vertical readout time*

$t_2 = 2\mu s$: *Time between vertical and horizontal readout*

$M_0 = 256$: *Horizontal size of the sensor*

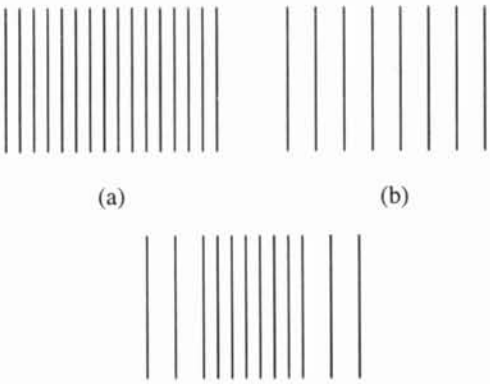
M_1 : *Horizontal resolution*

N : *Number of rows used in FBM*

A typical value of N is 8. If the horizontal resolution is 256 this gives us a line frequency of 17 kHz which corresponds to 4.3 MRangles.

An advantage using this approach is that we can trade resolution for speed. Normally, we use full horizontal resolution, represented in Figure (a). For instance we can reconfigure our sensor to be an array of 64 columns where each column actually consists of 8 columns, represented by

Figure 6(b). This means that the SNR and the line frequency increases (25 kHz) while the number of Rangles decreases to 1.6 MRangles. One very useful advantages of this feature is that we can have different resolutions on different parts of the sensor. For instance, we can have higher resolution in the center which corresponds to Figure 6(c).



(a) (b) (c)

Figure 6, Different spatial resolutions

The effect when we perform an analog summation of two neighboring column after the vertical readout, is the same as if we performed the analog addition before the vertical readout which can be described as

$$
\begin{aligned}
& f_F(x) + f_F(x+1) = \\
& = \sum_i i \cdot f(x, i) + \sum_i i \cdot f(x+1, i) = \\
& = \sum_i i \cdot (f(x, i) + f(x+1, i)) \qquad (6)
\end{aligned}
$$

The range resolution is not primarily dependent on the number of rows but on the resolution of S1 and S2. In the previous reported implementation of FBM, which is on the MAPP2200 sensor, the resolution is 8 bit due to the design of the MAPP2200 chip in which there are 256 internal AD-converters. In the CIVIS system it is possible to use one external high resolution ADC, for instance 10 bits. This will favor this implementation to the MAPP2200 implementation.

3 Results

Figure 7 shows the gray scale image of a computer mouse which has been moved under the laser line. The gray scale image corresponds to Equation (3).

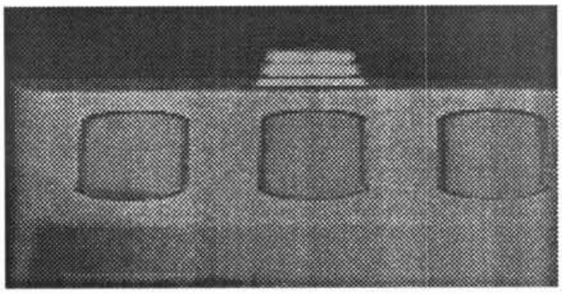


Figure 7, Gray scale image

Figure 8 is obtained from the same sequence and it is the range to the object, which corresponds to Equation (4). The brighter area the higher is the pixel below the surface.

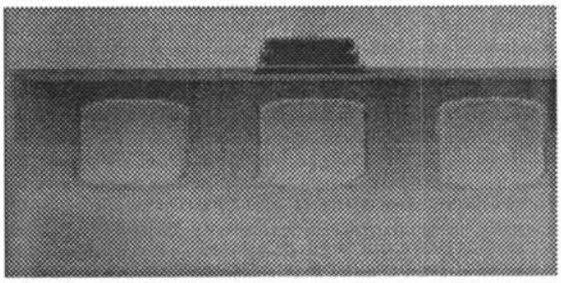


Figure 8, Range image

Figure 9 is a 3D visualization of the range image. Here data with low intensity in the gray scale image has been removed from the range image.

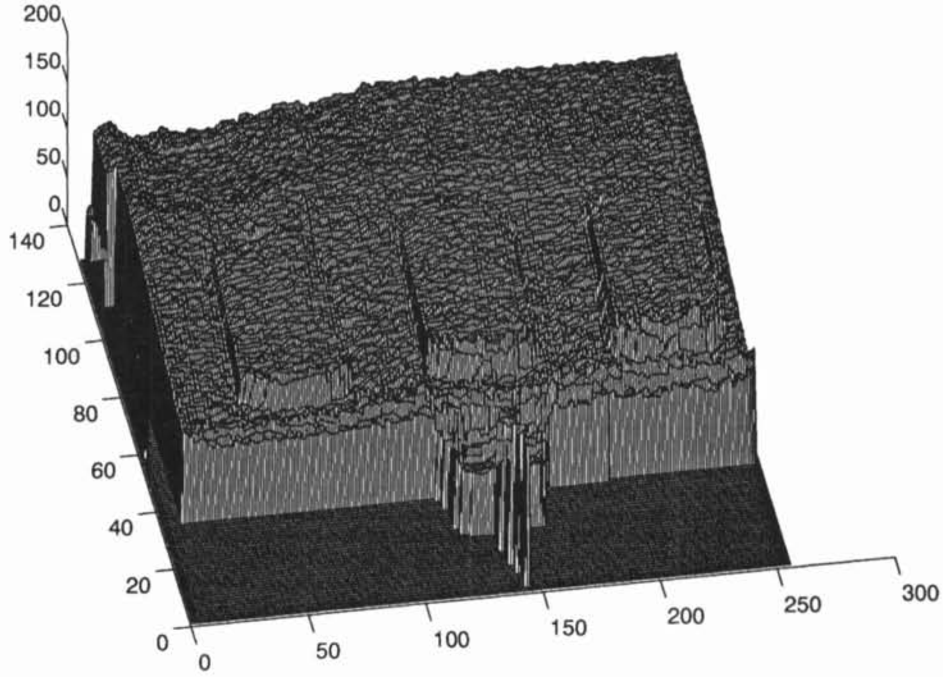


Figure 9, A 3D visualization of the range image

4 Conclusions

To conclude, this CIVIS implementation stretches a bit further the limits for very fast SOL range imaging. The multi resolution possibilities in the CIVIS chip is very useful in industrial application where the speed and resolution requirements can change both over time and along the inspection line. The possibility to have a high precision ADC and the lack of digital part on the chip, which can cause digital noise, also favors the CIVIS chip to the MAPP2200 chip.

5 Acknowledgements

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