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A Visual Circuit for Lateral Motion Detection

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Abstract- **This paper presents a design and implementation of an intelligent vision chip for detecting lateral object motion. We propose a correlation interconnection scheme for the outputs of a photocircuit array to infer motion direction of nearby objects as well as the tendency of approaching of a moving object. This design facilitates lateral obstacle avoidance of an intelligent vehicle. The circuit has been successfully simulated by Hspice and integrated into a sensor chip of 20×20 pixel array. The vision chip has been fabricated with TSMC 0.35 μm 2P4M CMOS process. The chip area is 2.48 mm ×2.42 mm. The function of photocells, registers and correlation in extreme cases are verified.**

I. Introduction

Motion detection is an important issue for intelligent vehicles [1]-[5]. Vision sensors onboard vehicles can monitor environments during driving and help the driver to prevent from accidents. For practical applications, it will be interesting to use an intelligent CMOS image sensor for driver safety assistance. This type of sensors feature low power consumption, small size and providing rich information. From literature survey, there have been many studies aimed at real-time processing exploiting analog hardware implementations of integrated chips for image capture and motion detection. Yamada and Soga proposed a vision chip based on correlation-based algorithm[6]. The pixel array of the design is 10×2 pixels. The die size is 2mm×2mm . Their design can detect the velocity and direction of moving objects. In [7], Wu and Huang proposed a design of a CMOS focal-plane motion sensor with BJT-based retinal smoothing network and modified correlation-based algorithm. Theie design can detect the velocity and direction of a moving object. However, the calculations of velocity and direction of moving object are processed by off-chip software. Further, the interconnection of correlation is connected to four directions, +X,-X,+Y and –Y. The tendency of approaching, which is useful for lateral driver assistance, cannot be detected by this kind of connection. If the interconnection of correlation is modified, it is possible to detect the information of approaching onboard he vehicle.

In this paper, a vision chip for lateral motion detection is proposed. The proposed design can detect the motion by a sensing pixel array. The sensing data can be calculated immediately by processing circuit which is integrated on-chip. The real-time processing is useful for intelligent vehicle applications.

II. Motion Detection Method

In this study, a correlation-based approach is adopted for motion detection circuit design. The conceptual diagram of correlation-based algorithm is shown as Fig 1. In Fig. 1, PH represents photocircuit. The output of PH is a binary value represented by a voltage. The circuit outputs either a voltage high, when the photocircuit detects a moving object or voltage low if there is no moving object. REG and D in Fig. 1 are realized by registers. The function of REG is to store the output voltage from PH. And the function of D is to generate a time delay . C is a correlator realized by the AND gate. SR represents a shift register.

Fig. 1 and Fig. 2 explain the operation principlel of the correlation circuit. As shown in the figures, consider the case that an object is moving in front of the sensor from PH2 to PH3. At instant T1, the object is in the position as shown in Fig 1 . PH2 detects the object and outputs a voltage high to REG2. At this moment, D1,D2 and D3 store logic 0 and the outputs of C1,C2 and C3 are also logic 0. After shifting by SR1,SR2 and SR3 , one obtain the shift_output as 0,0,0 . At instant T2 , the object moves from PH2 to PH3 as shown in Fig 2. PH3 detects the object and outputs a voltage high to REG3. The outputs of REG3 and D2 are all logic 1. Therefore, the output of C3 will be logic 1. After shifting by SR1,SR2 and SR3, the shift_output is 0,0,1. From the output, it can be determined that there is an object moving from left to right according to the shifting result of correlation interconnection in the duration from T1 to T2. In the proposed design, the correlation interconnection contains six directions, namely left(L) , right(R) , upper left(LU) , upper right(RU) , lower left (LD) and lower right(RD) as shown in Fig. 3. As explained latter, these six directions allow us to determine whether a vehicle is approaching from behind or from front.

As for the image sesnor array, Fig. 4 shows an example of 5×5 pixel array. Suppose an object is detected to occupy fourpixels as shown in Fig. 4. And the object moves one pixel to right in the duration from T1 to T2. As shown in Fig. 4 , the black pixel represents the output of the pixel is logic 1. The output of correlation in right direction(R) is 4 which is accumulated by T1(2,2) AND T2(2,3) ; T1(2,3) AND T2(2,4) ; T1(3,2) AND T2(3,3); and T1(3,3) AND T2(3,4). The output of correlation in upper right direction (RU) is 2, which is accumulated by T1(3,2) AND T2(2,3); and T1(3,3) AND T2(2,4) . Therefore, the outputs of RD , L , LU and LD can be

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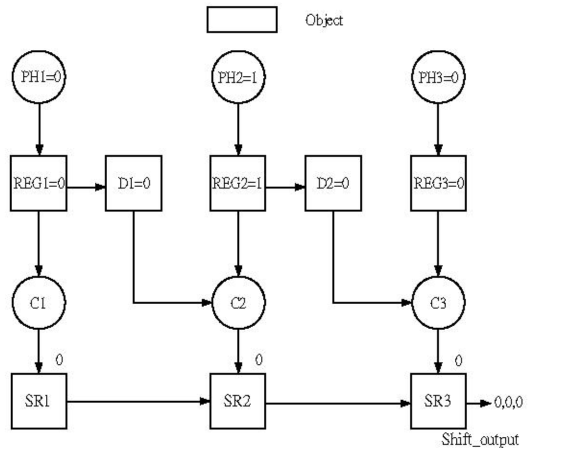

Fig. 1. The photo receptor correlation design; an object is passing photocell PH2 at instant T1

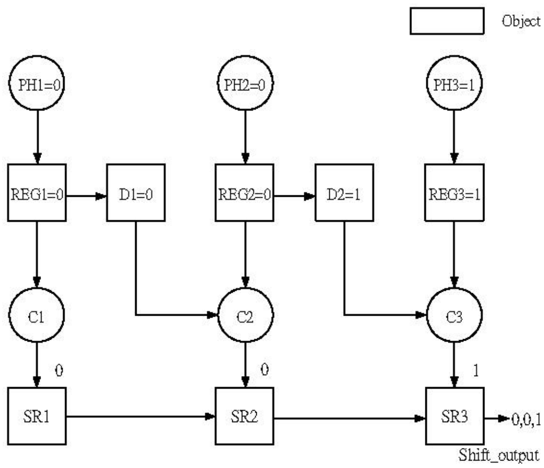

Fig. 2. An object is passing photocell PH3 at instant T2

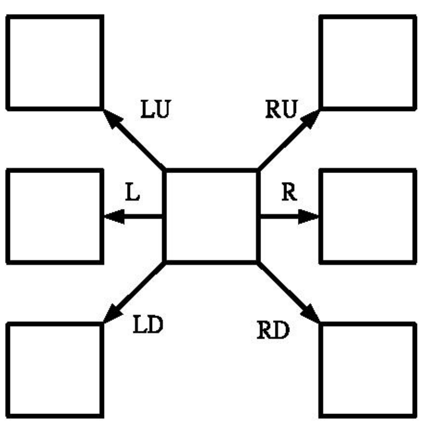

Fig. 3. The correlation connection of photocells

obtained as shown as Fig. 4 . The output R(=4) is the maximum of these six outputs. This indicates the object motion direction is to the right.

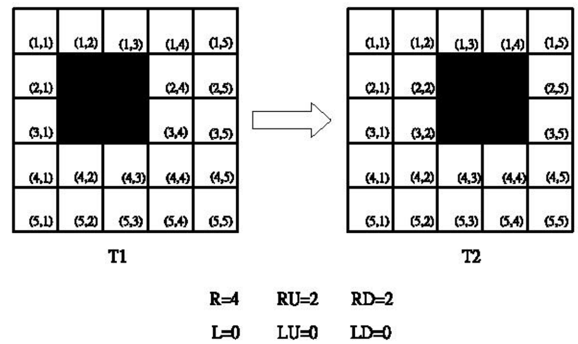

Fig. 4. An example of correlation

For lateral-vehicle detection, there are six possible situations as shown in Figs. 5-6. These situations show possible tendency of approaching caused by a nearby object(vehicle). In Fig. 5(a), the moving object will pass the image sensor from behind. From the viewpoint of the image sensor, the object will be detected to move from left to right. In Fig. 5(b), the moving object approaches the image sensor from behind and is approaching. In Fig. 5 (c), the moving object is from behind and moving away. Fig. 6 depicts similar situations as those depicted in Fig. 5, but the object is approaching from front.

In Figs.7-9, simulated binary values of pixel arrays of the image sensor are used to illustrate the sensor data for situations in Figs. 5 (a)-(c) respectively. In the figures, black rectangles denote logic 1 and represent the sensed image of a moving object. The image sensor in the situation of Fig. 5(a) is shown in Fig. 7. As Projected on the image sensor, the object is moving from right to left. The image of the situation in Fig. 5(b) sensed by the image sensor is shown in Fig. 8. In this case, as projected on the image sensor, the object is moving from upper right to lower left. The case of Fig. 5(c) is shown in Fig. 9. In Fig. 9, the object sensed by the image sensor is moving from lower right to upper left.

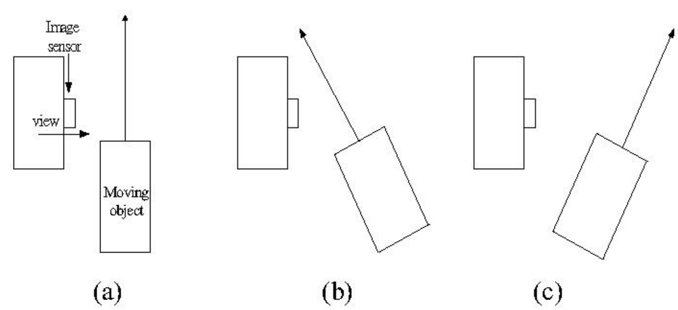

Fig. 5. The situations of a vehicle approaching from behind

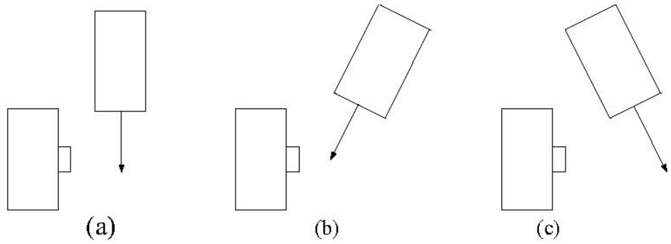

Fig. 6. The situations of a vehicle approaching from front

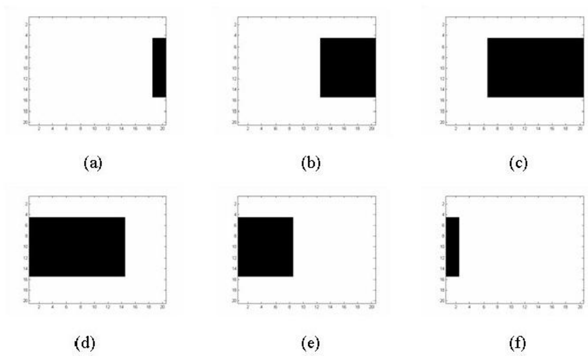

Fig. 7. The view of the image sensor in Fig 5(a)

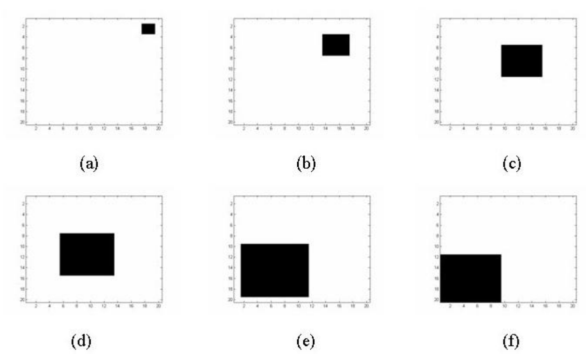

Fig. 8. The view of the image sensor in Fig 5(b)

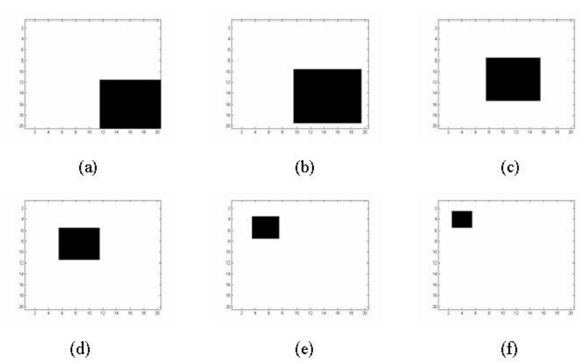

Fig. 9. The view of the image sensor in Fig 5(c)

The sdetection of the sensor array for six situations of Figs. 5-6 have been simulated using MATLAB. Only the results of three cases of Fig. 5(a)-(c) are presented for discussion. The corresponding simulation results are shown in Table I-III, respectively. The simulation was emulated with an image sesnsor of 20x20 pixal array. In Table I, there are six output values. Output L represents the number of correlated pixels in left direction . Outputs R, LU, LD, RU, and RD represent the number of correlated pixels in right, upper left, lower left, upper right and lower right directions respectively. The simulation result of the situation of Fig. 5(a) is listed in Table I. In Table I, sequence 1 represents the output of the image change from Fig. 7(a) to (b). Sequence 2 represents the output of of the image change from Fig. 7(b) to (c), and so forth. As expected, corresponding to the moving direction in Fig. 7, the output L is the maximum among all the outputs. Similarly, the simulation result of the situation in Fig. 5(b) is listed in the Table II. In Table II, output LD is the maximum among all the outputs. And the image change of situation in Fig. 5(b) is shown in Fig. 8. It shows that the object is moving to lower left direction whose output value is the maximum. The simulation results of the situation in Fig.5(c) is listed in Table III.

TABLE I
THE SIMULATION RESULT IN FIG 5(A)

Sequence		L	R	LU	LD	RU	RD
1	(a)to(b)	22	11	20	20	10	10
2	(b)to(c)	88	77	80	80	70	70
3	(c)to(d)	99	77	90	90	70	70
4	(d)to(e)	88	77	80	80	70	70
5	(e)to(f)	22	11	20	20	10	10
6		0	0	0	0	0	0

TABLE II
THE SIMULATION RESULT IN FIG 5(B)

Sequence	L	R	LU	LD	RU	RD
1	2	0	0	4	0	0
2	6	2	3	9	1	3
3	12	6	8	16	4	8
4	20	12	15	25	9	15
5	30	20	24	36	16	24
6	42	30	35	49	25	35
7	56	42	48	64	36	48
8	72	56	63	81	49	63

TABLE III
THE SIMULATION RESULT IN FIG 5(C)

Sequence	L	R	LU	LD	RU	RD
1	90	72	100	80	80	64
2	72	56	81	63	63	49
3	56	42	64	48	48	36
4	42	30	49	35	35	25
5	30	20	36	24	24	16
6	20	12	25	15	15	9
7	12	6	16	8	8	4
8	6	2	9	3	3	1

According to the maximum output value, one can infer that the object is moving to right. Therefore, the direction of moving object can be detected by observing the correlation outputs. The object will be detected to move in the direction whose accumulating number of correlated pixels is the maximum.

III. Architecture of Vision Chip

The proposed architecture of the CMOS vision chip is shown in Fig. 10. In Fig. 10, the CMOS image sensor is composed of a 20×20 pixel array. The structure of each pixel cell is shown in Fig. 11. Each pixel cell contains a photocircuit. The sensing element of the photocircuit is realized by N+/PWELL type photodiode. Photocircuit converts the light intensity to voltage. The outputs voltage of photocircuit shifts to two levels by a voltage comparator. The register1 stores the current binary voltage. The delayed binary voltage, which is generated by clock control and register2, shifts to six neighboring pixels for correlation. The interconnection of six neighboring pixel is shown in Fig. 12. There are six correlators in Fig. 11 due to six correlation directions. The outputs of correlators are shifted to the output of vision chip by shift-registers. The timing diagram of the circuit is shown in Fig. 13. In the Fig. 13, CLK1 and CLK2 are delivered to the vision chip. The photosensing is processed when CLK1 goes high. The correlation is processed when CLK1 changes from high to low. When the signal LOAD/SHIFT is in low state, the shift-register is in the LOAD mode. When the signal LOAD/SHIFT is in high state, the shift-register is in the SHIFT mode, and shifts the correlation outputs to the output-pins of the chip.

IV. Circuit Design and Hspice Simulation

In order to verify the design of the motion detection circuit, A Hspice simulation has been conducted. The Hspice simulation result of the shift registers is illustrated in Fig. 14. In the simulation of shift registers, three shift-registers are cascaded. The inputs load-in when LOAD/SHIFT is in low-level and shift when LOAD/SHIFT is in high-level. The simulation results meet the required performance as expected.

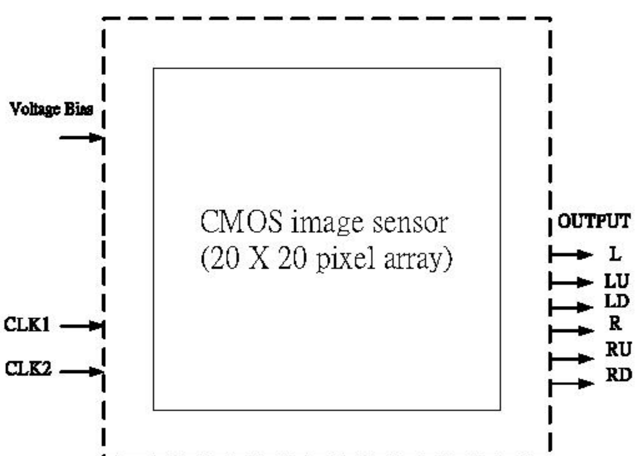

Fig. 10. Architecture of vision chip

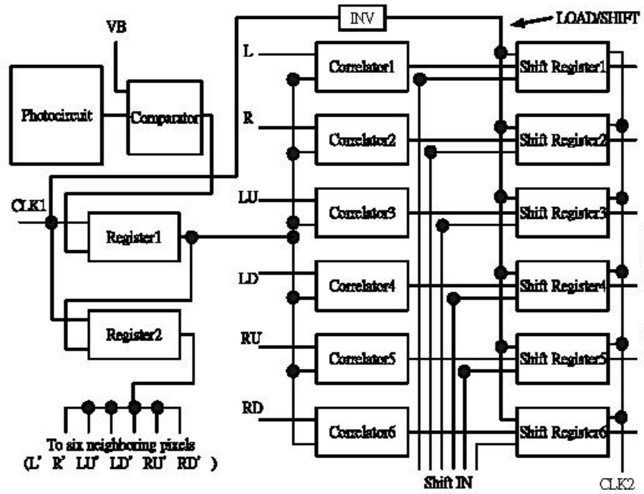

Fig. 11 . The structure of single pixel cell

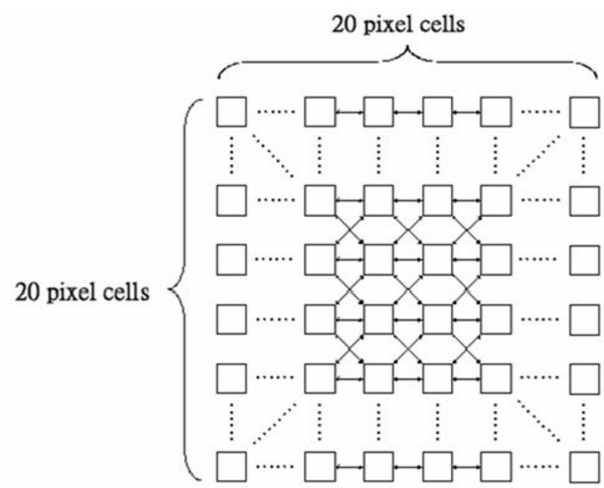

Fig. 12. The interconnection of correlation

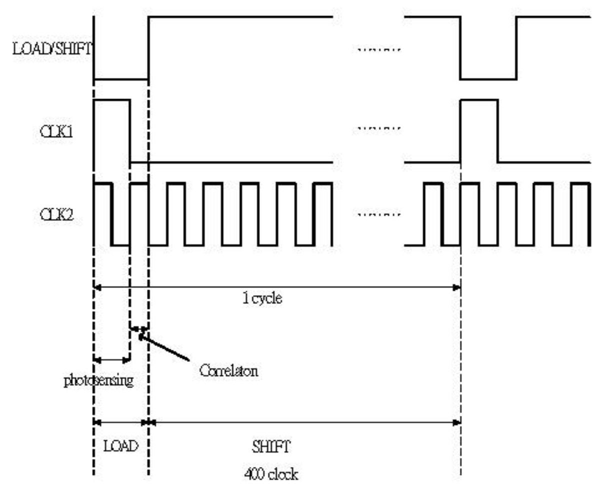

Fig. 13 . The timing diagram

A 4 ×4pixel array is shown in Fig. 15 for motion detection simulation. The simulation result is shown in Fig. 16. We simulated a moving object to move from left to right from instant T1 to instant T2. In Fig. 16, the number of pulses of SOR(Sensor Output Right) between T1 to T2 is two, which is the maximum number. By observing the maximum output, one can know that the object is moving to the right direction. The simulation confirms the designed results. The expected specification of the vision chip is shown in Table IV.

V. TESTING RESULT

The motion detection vision chip was fabricated by the help of Chip Implementation Center (CIC), Taiwan. We first tested the photocircuit. The incident light was supplied by using an integrating sphere. The output of the vision chip is connected to a PC via a data acquisition card, a NI-DAQ card. A Labview program handled the counting of pulse number of six outputs of vision chip. The testing result of the photocircuit is shown in Fig. 17. In the test, the intensity of incident light scattered to the chip is controlled from low to high. The output voltage of the photocircuit is inverse proportion to the intensity. The result validates the simulation. The testing result of the register is shown in Fig. 18. The output follows the input in the negative edge of the clock. The result also validates the simulation.

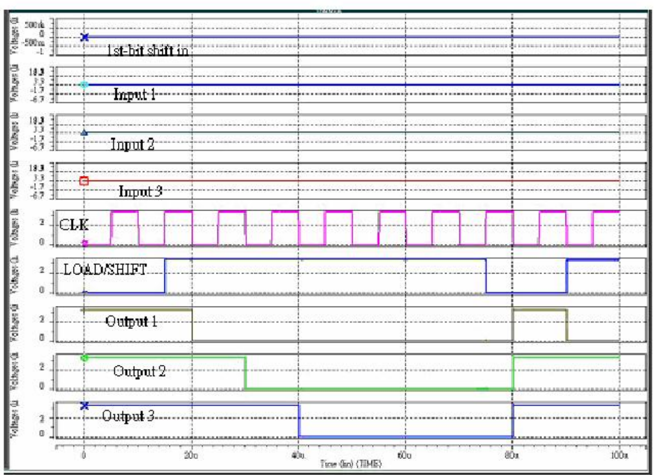

Fig. 14. The simulation of the shift-register

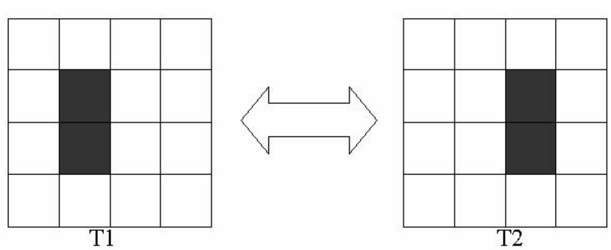

Fig .15. The simulation condition

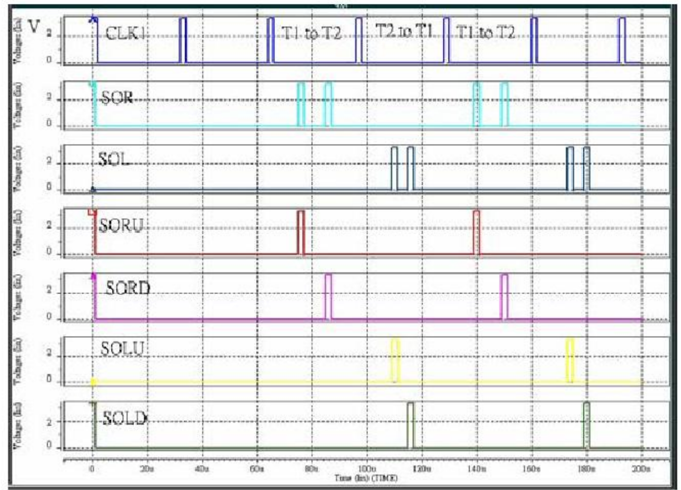

Fig .16. The simulation of moving object

TABLE IV
THE EXPECTED SPECIFICATION

Technology	TSMC 0.35um 2P4M Mixed Signal
Power Supply	3.3V
Array size	20 × 20
Cell area	98 × 103μm2
Photosensor fill factor	9.7%
Maximum Readout Speed	1250 frames/s
Total power consumption	136 mWatt
Operating Temperature	25℃
Die size	$2.48 \times 2.42\ mm^2$

VI. CONCLUSION

In this paper, a vision chip for lateral motion detection has been designed and simulated. We proposed a correlation interconnection of the outputs of a photocircuits array to infer object motion direction as well as the tendency of approaching of the object. This type of intelligent sensor will be useful for lateral vehicle detection for driver safety assistance. In this study, analog VLSI technique has been employed to design and implement the circuits for real-time and stand-alone performance. The proposed circuit has been successfully simulated by Hspice and integrated into a 20×20 pixel array sensor chip. The vision chip is fabricated with TSMC 0.35 μm 2P4M CMOS process. The chip area is 2.48 mm ×2.42 mm. After testing, the function of photocells and registers have been verified. In the future, improvement on the photocircuit will be studied for more robust results. System integration with a motion platform will be investigated for practical applications.

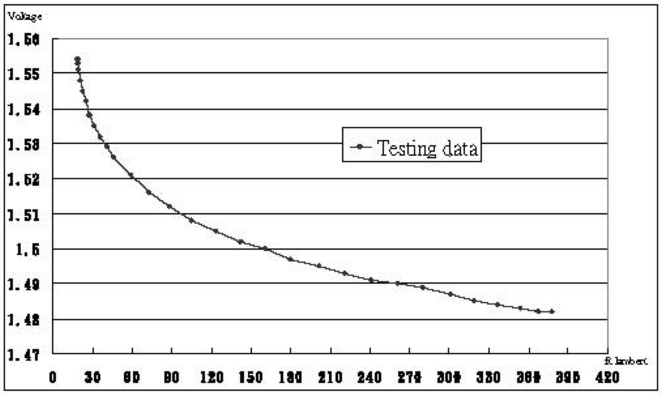

Fig. 17. The testing result of voltage comparator

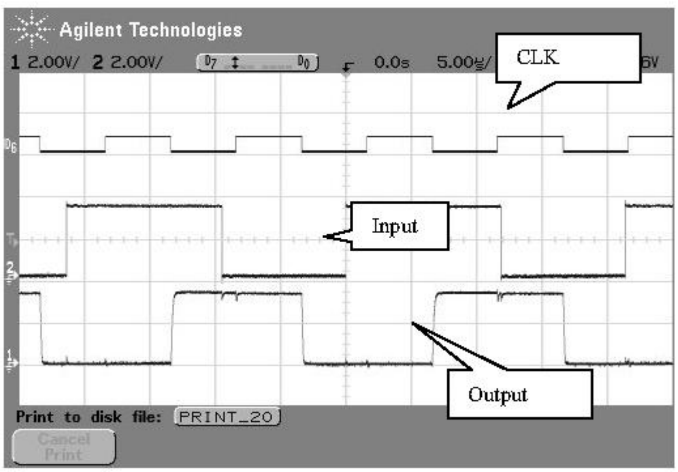

Fig.18. The testing result of the register with a clock of 300KHz

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REFERENCES

[1] Haitao Li, Samir Bouaziz and Francis Devos, "An embedded system forantonomous collision avoidance and line tracking using artificial CMOS retina sensor," *IEEE Intelligent Vehicles Symposium* , pp. 279-283, 2000.

[2] I. Masaki, "Machine-Vision Systems for Intelligent Transportation Systems," *IEEE Intelligent Systems*, Vol. 13 , No. 6, pp. 24-31, 1998.

[3] Bertozzi, A. Broggi, M. Cellario, A. Fascioli, P. Lombardi and M. Porta, "Artificial Vision in Road Vehicles," *Proceedings of the IEEE*, Vol. 90, pp. 1258 1271, 2002.

[4] National Highway Traffic Safety Administration, "*Automotive collision Avoidance Systems (ACAS) Program*," NHTSA Final Report, 2000

[5] W. Kruger, W. Enkelmann and S. Rossle, "Real-time estimation and tracking of optical flow vectors for obstacle detection,"*in Proceeding of IEEE* IV, pp. 304-309, 1995.

[6] Keiichi Yamada and Mineki Soga, "A Compact Integrated Visual Motion Sensor for ITS Applications," *IEEE Intelligent Vehicles Symposium*, pp. 650-655, 2000.

[7] C.Y. Wu and K.H. Huang, "A CMOS focal-plane motion sensor with BJT-based retinal smoothing network and modified correlation-based algorithm," *IEEE Sensors Journal*, vol. 2, no. 6, pp. 549-558, December 2002.