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International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

FPGA Based Object Detection for Autonomous Vehicles

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A B S T R A C T

The present transportation world is moving towards the driverless and self-driving autonomous vehicles. This type of vehicle design requires a lot of methods in identification of objects in terms of living and non-living categories. The Autonomous driving systems require a real-time detection of the objects including pedestrians and obstacles on the roads. The Object detection using image processing is a popular approach for autonomous driving systems. However, there are complex reflections caused by multiple light sources and objects on the roads, which disturb the robust and real-time object detection.

The real-time processing of tracking white-lines for lane-keeping and obstacles or pedestrians' detection on the roads are executed by the hardware on the programmable logics, and the whole system is controlled by a software. This paper describes an FPGA-based object detection method for autonomous driving systems using multiple cameras. The proposed system is designed by using Verilog HDL targeting for Xilinx Spartan-3 FPGA for different test cases of living human beings and non-living categories.

Keywords: Autonomous Vehicles, FPGA, Object Detection, Self driving, Verilog HDL

1. Introduction

The transportation is the best way to move from one place to another place for day to day activities in the present world. The need for transportation is increasing in terms of number of vehicles year by year [1]. This increase in number of vehicles is leading to heavy traffic and more chances for road accidents due to human mistakes. The possible human mistakes and errors for road accidents are like inefficiency of driver's driving skills while driving, less concentration during driving, lights reflection etc. All these issues are making the driver for misinterpretation of object identification and detection on the roads, which is leading towards road accidents and causing deaths.

To overcome these problems for human safety and security, the driverless or autonomous vehicles is one solution. The driverless autonomous vehicle reduces the life-threatening condition of driver and reduces the number of mistakes as compared to the human driver-based vehicle. There are different challenges are involved in creating the design of autonomous vehicles. The challenges include identification of road boundaries, lane tracking, object identification and detection during the driving mode, checking fuel, air status in tyres, checking all the people have entered the vehicle before starting, speed controlling, etc.

In the design of autonomous vehicles, the object identification and detection are the major task for safety and secured driving with a smaller number of accidents. This design uses the objects as living objects and non living objects. This paper gives the design and analysis of FPGA based object detection for autonomous vehicles.

The section 2 gives the design analysis of object detection, Section 3 gives the implementation of FPGA based object detection, Section 4 gives the simulation results of different test cases, the section 5 gives the conclusion followed by references.

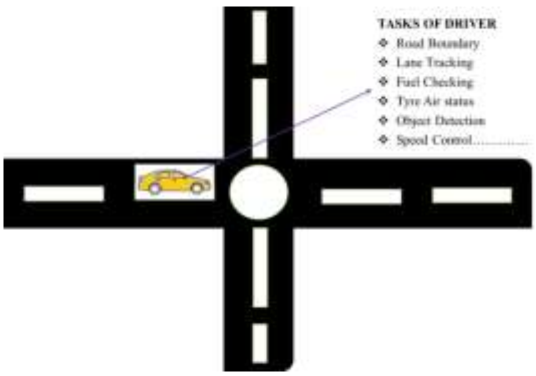

Figure 1: Tasks of a driver

2. Design Analysis

The present human based driving environment consist of no automation or driver assistance or partial driving automation. The design of autonomous vehicles-based driving uses conditional driving or full driving automation [2]. The design of autonomous vehicles should have the control over break, clutch, speed, and accelerator control as per the object's movement. The objects are grouped and classified into two groups as non living and living objects. The object detection is done by using the following procedure as shown in Figure 2[3].

1. Image captured from camera

2. Image conversion into NxN pixel matrix

3. NxN image matrix to 3x3 or 5x5 pixel matrix conversion

4. Object Detection 3x3 matrix

The input image of an autonomous vehicle is captured by using the camera sensor. This image is converted into NxN pixel matrix i.e. for example 256x256 matrix. As the processing of 256x256 image needs more computation time and large number of resources, this image is further classified into creation of 3x3 or 5x5 pixel matrix as per the application and available resources. In this design a 3x3 matrix is selected for faster computation of object detection. This 3x3 matrix is utilized for the detection of an object as living or non-living object by FPGA based object detection system. The following figure 3 shows the classification of different objects/classes. The figure 3 shows the classification into non living objects that are considered as, all vehicles of two-wheelers, light vehicles, heavy vehicles category [4]. The living objects are considered as humans.

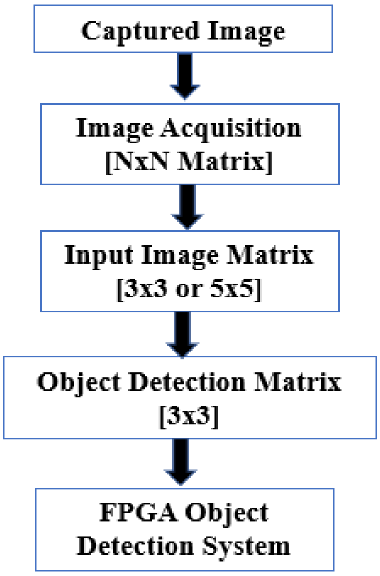

Figure 2. Calculation of Object Detection Matrix

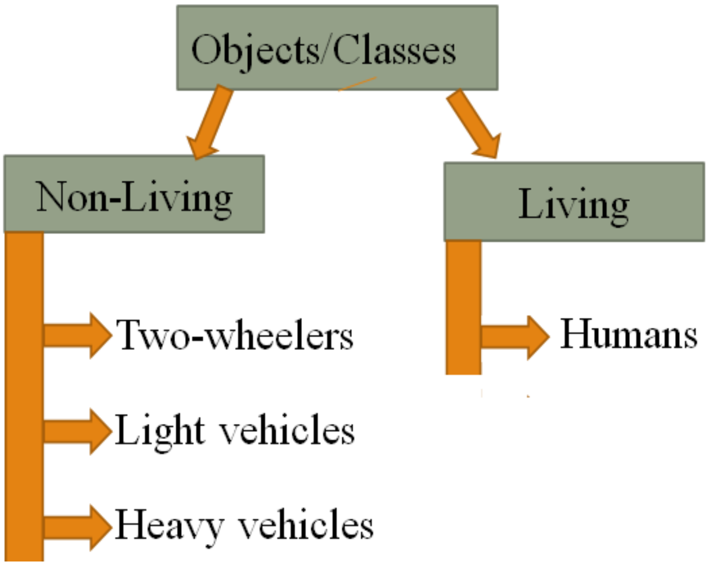

Figure 3. Classification of Objects

These objects are used with an identification matrix for their detection and stored in the form of dataset for object detection of an autonomous vehicles [5]. The following table 1 shows the information about the dataset of these objects.

Table 1. Dataset for object Detection

S. No	Object detection type	Binary equivalent	Unique pattern from n*n matrix
1.	Two wheeler	100101100	300
2.	Two wheeler	100101101	301
3.	Light vehicle	100101110	302
4.	Light vehicle	100101111	303
5.	Light vehicle	100110000	304
6.	Light vehicle	100110001	305
7.	Heavy vehicle	100110010	306
8.	Heavy vehicle	100110011	307
9.	Human	100110100	308
10.	Human	100100101	309

3. Implementation

The flowchart or design algorithm for implementation of object detection is as follows:

1. The image is captured from the external camera through sensors.

2. The captured image is then sent to the Digital processing unit.

3. The digital processing unit acts on this image with the aim to map it in a convenient matrix for further analysis in the flow, in this design 3*3 matrix is identified as the convenient matrix for analysis.

4. The two-dimensional captured image's concerned side is viewed as n*n matrix i.e. 256*256 matrix.

5. For analysis, digital processing unit divides this n*n matrix into 8*8 matrices.

6. For each class of objects central part/region of interest is identified.

7. Analysis is carried out for various images of same class using the above flow steps for better object detection process.

8. After analysis, the unique patterns for the respective classes are obtained and are curated in the central database for further implementation.

The following table 2 gives the details about the input test dataset values for object detection. The outputs for the object detection presence are identified as a two wheeler, light vehicle, heavy vehicle, human by using logic-1. Similarly, the absence of these objects is identified by using logic-0. According to the logic levels of these objects the autonomous vehicle will move or stop.

Table 2. Test dataset function table for object Detection

S. No	X	Two	light	Heavy	Human	Stop	move
1	300	1	0	0	0	1	0
2	301	1	0	0	0	1	0
3	302	0	1	0	0	1	0
4	303	0	1	0	0	1	0
5	304	0	1	0	0	1	0
6	305	0	1	0	0	1	0
7	306	0	0	1	0	1	0
8	307	0	0	1	0	1	0
9	308	0	0	0	1	1	0
10	309	0	0	0	1	1	0
11	506	0	0	0	0	0	0
12	0	0	0	0	0	0	1

Assumptions:

- Always vehicle is assumed to be in moving direction
- Vehicle always moves in the center of the road following the road regulations [6].
- The control system is trained to detect only ten images of living and non-living things.

The figure 4 shows the block diagram of object detection system with the input as 3x3 matrix with 9-bit value as X. The outputs are indicated as two wheeler, light vehicle, heavy vehicle, human, stop and move. The Object Detection System is designed by using Verilog HDL with Xilinx ISE EDA tool. The synthesis top level RTL schematic of Object Detection System is shown in Figure 5. The internal synthesis top level RTL schematic of Object Detection System gives the detailed information about the logic Look Up Tables and other resources that are used for FPGA realization of object detection system.

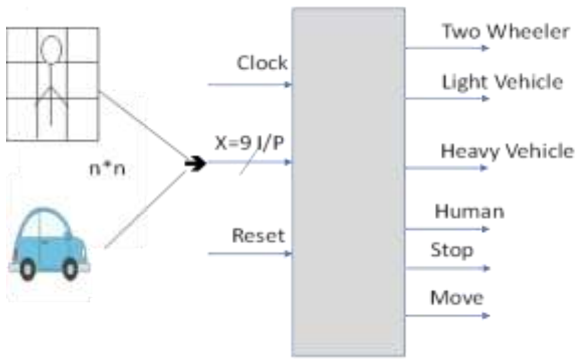

Figure 4. Block diagram of Object Detection System

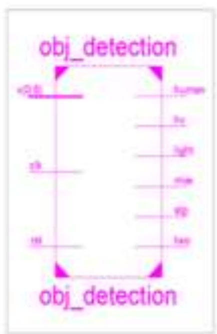

Figure 5. RTL Schematic of Object Detection System

4. Simulation Results

The FPGA based object detection system is designed by using Verilog HDL and Xilinx EDA tool. This system is tested for different test cases using Verilog HDL testbench with the help of Xilinx ISE simulator tool. The detailed information about different test cases and their corresponding results to move/stop the vehicle are shown below [7].

Test case 1:

The simulation result for test case 1 is shown in Figure 6. It is observed that the vertical line highlights the input, having '300' as the decimal equivalent. This input triggers the outputs 'two' and 'stop' i.e., they are switched to logic '1' with the given input. Hence the given input is detected as a two-wheeler and the action command 'stop' is triggered in the vehicle system.

Test case 2:

The simulation result for test case 2 is shown in Figure 7. It is observed that the vertical line highlights the input, having '301' as the decimal equivalent. This input triggers the outputs 'two' and 'stop' i.e., they are switched to logic '1' with the given input. Hence the given input is detected as a two-wheeler and the action command 'stop' is triggered in the vehicle system.

Figure 6. Simulation Result of Test case 1 for Object Detection System

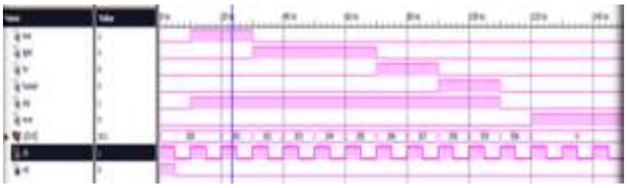

Figure 7. Simulation Result of Test case 2 for Object Detection System

Test case 3:

The simulation result for test case 3 is shown in Figure 8. It is observed that the vertical line highlights the input, having '302' as the decimal equivalent. This input triggers the outputs 'light' and 'stop' i.e., they are switched to logic '1' with the given input. Hence, the given input is detected as a light-duty vehicle and the action command 'stop' is triggered in the vehicle system.

Test case 4:

The simulation result for test case 4 is shown in Figure 9. It is observed that the vertical line highlights the input, having '303' as the decimal equivalent. This input triggers the outputs 'light' and 'stop' i.e., they are switched to logic '1' with the given input. Hence, the given input is detected as a light-duty vehicle and the action command 'stop' is triggered in the vehicle system.

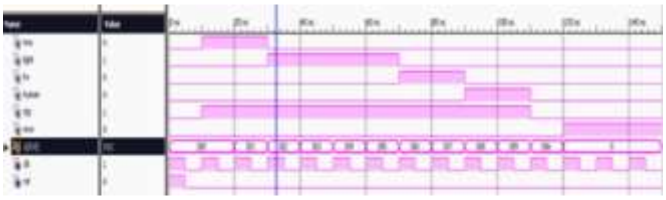

Figure 8. Simulation Result of Test case 3 for Object Detection System

Figure 9. Simulation Result of Test case 4 for Object Detection System

Test case 5:

The simulation result for test case 5 is shown in Figure 10. It is observed that the vertical line highlights the input, having '304' as the decimal equivalent. This input triggers the outputs 'light' and 'stop' i.e., they are switched to logic '1' with the given input. Hence the given input is detected as a light-duty vehicle and the action command 'stop' is triggered in the vehicle system.

Test case 6:

The simulation result for test case 6 is shown in Figure 11. It is observed that the vertical line highlights the input, having '305' as the decimal equivalent. This input triggers the outputs 'light' and 'stop' i.e., they are switched to logic '1' with the given input. Hence the given input is detected as a light-duty vehicle and the action command 'stop' is triggered in the vehicle system.

Figure 10. Simulation Result of Test case 5 for Object Detection System

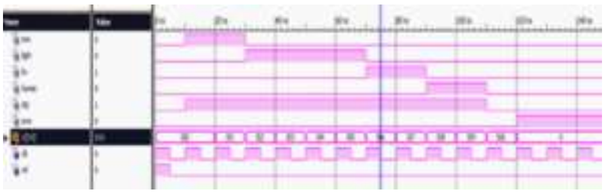

Figure 11. Simulation Result of Test case 6 for Object Detection System

Test case 7:

The simulation result for test case 7 is shown in Figure 12. It is observed that the vertical line highlights the input, having '306' as the decimal equivalent. This input triggers the outputs 'heavy' and 'stop' i.e., they are switched to logic '1' with the given input. Hence the given input is detected as a heavy vehicle and the action command 'stop' is triggered in the vehicle system.

Test case 8:

The simulation result for test case 8 is shown in Figure 13. It is observed that the vertical line highlights the input, having '307' as the decimal equivalent. This input triggers the outputs 'heavy' and 'stop' i.e., they are switched to logic '1' with the given input. Hence the given input is detected as a heavy vehicle and the action command 'stop' is triggered in the vehicle system.

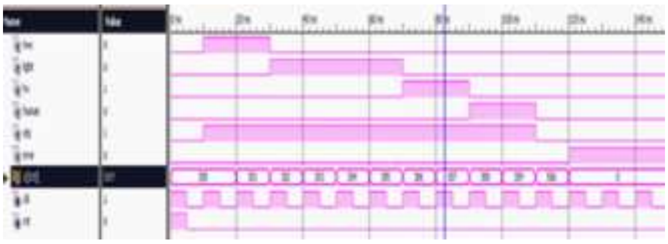

Figure 12 Simulation Result of Test case 7 for Object Detection System

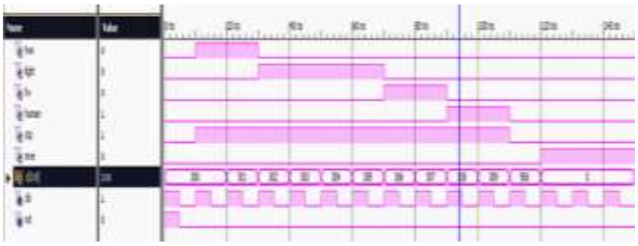

Figure 13 Simulation Result of Test case 8 for Object Detection System

Test case 9:

The simulation result for test case 9 is shown in Figure 14. It is observed that the vertical line highlights the input, having '308' as the decimal equivalent. This input triggers the outputs 'human' and 'stop' i.e., they are switched to logic '1' with the given input. Hence the given input is detected as human and the action command 'stop' is triggered in the vehicle system.

Test case 10:

The simulation result for test case 10 is shown in Figure 15. It is observed that the vertical line highlights the input, having '309' as the decimal equivalent. This input triggers the outputs 'human' and 'stop' i.e., they are switched to logic '1' with the given input. Hence the given input is detected as human and the action command 'stop' is triggered in the vehicle system.

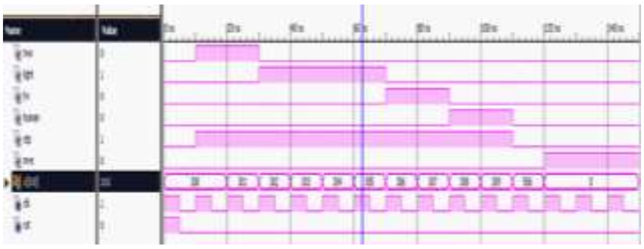

Figure 14 Simulation Result of Test case 9 for Object Detection System

Figure 15 Simulation Result of Test case 10 for Object Detection System

Test case 11:

The simulation result for test case 11 is shown in Figure 16. It is observed that the vertical line highlights the input, having '506' as the decimal equivalent. This input triggers none of the outputs i.e., all the outputs are switched to logic '0' with the given input.

Test case 12:

The simulation result for test case 12 is shown in Figure 17. It is observed that the vertical line highlights the input, having ‘0’ as the decimal equivalent. This input triggers the output ‘stop’ i.e., the output ‘stop’ is switched to logic ‘1’ with the given input. Hence the given input is detected as empty road and the action command ‘move’ is triggered in the vehicle system.

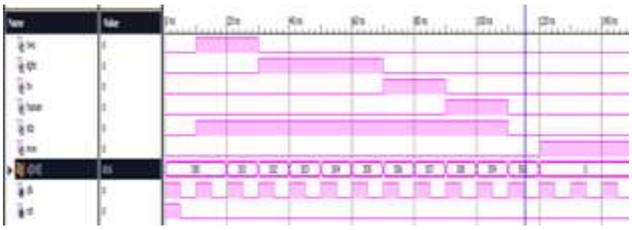

Figure 16 Simulation Result of Test case 11 for Object Detection System

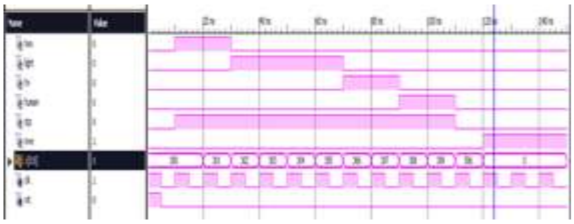

Figure 17 Simulation Result of Test case 12 for Object Detection System

5. Conclusions

This design described the FPGA-based object detection method for autonomous driving systems using multiple cameras. The proposed system is designed by using Verilog HDL targeting for Xilinx Spartan-3 FPGA for different test cases of living human beings and non-living categories. The designed system is tested for different testcases to detect the two wheeler, light vehicle, heavy vehicle etc, so that the autonomous vehicle will be in moving position or stop position. The proposed autonomous vehicle system will be extended by considering different testcases for further improvements for object detection.

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