FPGA BASED VEHICLE TO VEHICLE COMMUNICATION IN SPARTAN 3E

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Abstract

This paper presents economic and reconfigurable RF based wireless communication at 2.4 GHz between two vehicles. It implements digital VLSI using two Spartan 3E FPGAs, where one vehicle receives the information of another vehicle and shares its own information to another vehicle. The information includes vehicle's speed, location, heading and its operation, such as braking status and turning status. It implements autonomous vehicle technology. In this work, FPGA is used as central signal processing unit which is interfaced with two microcontrollers (ATmega328P). Microcontroller-1 is interfaced with compass module, GPS module, DF Player mini and nRF24L01 module. This microcontroller determines the relative position and the relative heading as seen from one vehicle to another. Microcontroller-2 is used to measure the speed of vehicle digitally. The resulting data from these microcontrollers are transmitted separately and serially through UART interface to FPGA. At FPGA, different signal processing such as speed comparison, turn comparison, distance range measurement and vehicle operation processing, are carried out to generate the voice announcement command, warning signals, event signals, and such outputs are utilized to warn drivers about potential accidents and prevent crashes before event happens.

Keywords: Vehicular communication, FPGA, Autonomous vehicle technology.

1. Introduction

Vehicular communication is one of the world wide latest and popular communication methods and rapidly emerging communication system along with the evolving technologies, such as artificial intelligence (AI) and internet of things (IoT). This has revolutionized the transportation system. It is also called as smart transportation. V2V is the acronym of the vehicle to vehicle communication, where vehicles are communicated to each other, emphasizing the prevention of road accidents.

Many cars already have instruments that use radar or ultrasonic obstacles or vehicles. These sensors are limited to few car lengths, and they cannot see past the nearest obstruction (Knight, 2015). The remarkable factor of this communication is wireless communication that can be implemented at low cost with efficient wireless communication protocol.

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There are many other activities, but it is certain that vehicle-to-vehicle communication has the potential to play a significant role in the future of safe driving (K. Farkas, 2006).If preventive measures are not taken road death is likely to change to the third-leading cause of death in 2020 from ninth place in 1990 (Peden, et al., 2004). A study from the American Automobile Association (AAA) concluded that car crashes cost the United States $300 billion per year (Anon., 2011).The deaths caused by car crashes are in principle avoidable. The U.S. Department of Transportation (DOT) states that 21,000 of the annual 43,000 road accident deaths in the US are caused by roadway departures and intersection-related incidents. Studies show that in Western Europe a mere 5 km/h decrease on average vehicle speeds could result in 25% decrease in deaths. V2V is currently in active development by General Motors, which demonstrated the system in 2006 using Cadillac vehicles. Automakers working on V2V includes BMW, Daimler, Honda, Audi, Toyota, Volvo and the Car-to-Car communication consortium (Vehicles, 2015). In December 2016, the US DOT proposed draft rules that would gradually make V2V communication capabilities to be mandatory for light-duty vehicles (Bigelow, 2017). The US automotive industry has said that it is willing to share the spectrum if V2V service is not slowed or disrupted and the FCC plans to test several sharing schemes (Press, 2016). With governments in different locales supporting incompatible spectra for V2V communication, vehicle manufacturers may be discouraged from adopting the technology for some markets. In Australia, there is no spectrum reserved for V2V communication, so vehicles would suffer interference from non-vehicle communications (Austroads, 2017).

2. Methodology

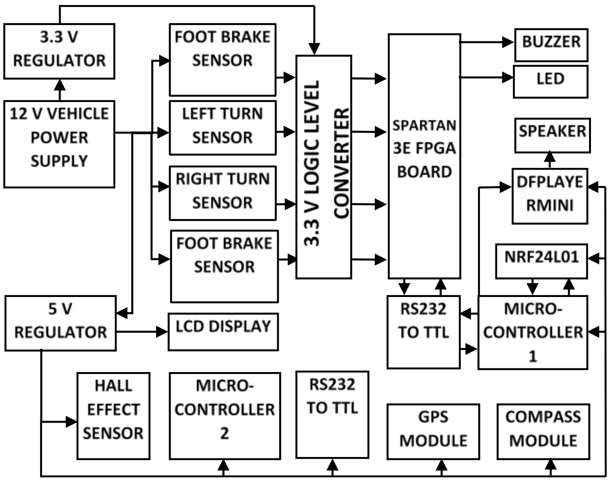


Fig.1 Block Diagram

The system has two major sections, viz. central section and peripheral section. Compass module, GPS module, nRF24L01 and DFPlayer mini are interfaced with microcontroller-1. This microcontroller determines relative position and relative heading, bidirectional wireless communication with another system, bidirectional serial communication with FPGA and finally voice command data transmission to DFPlayer Mini module. Compass measures the heading or the direction of this vehicle. GPS module gets the current position of this vehicle. The position and the heading of another vehicle are measured and are received by this microcontroller wirelessly. With the position of two vehicles, the relative position is determined through bearing measurement. And with the heading of two vehicles, the relative heading is determined. Finding relative position is not enough because another vehicle may have different heading or direction of motion. Along with position and heading of another vehicle, this microcontroller also receives other information, such as operation and speed of another vehicle. All of calculated data and other received information are transmitted to FPGA through serial communication by 8 bit binary coding. And in turn, microcontroller receives the voice command data along with other vehicular data from the FPGA. Finally, the measured value of heading and coordinates of this vehicle and FPGA data are collectively transmitted to another vehicle.

Microcontroller-2 is interfaced with Hall Effect sensor module and LCD. It simply measures the speed of vehicle by counting the revolution of vehicle's wheel. There are real time input data signals from two microcontrollers and different real time vehicular operation signal of this vehicle, such as braking signal, turning signal. These signals are taken from vehicle switches like Brake switches, Turn switches. To handle, analyze and process these signals, different VHDL modules are designed. Some of the major modules are speed comparison module, turn comparison module, distance range determination module, vehicular operation module, command generator module, LED signaling module, event and warning generator module and finally LED output module. After the signal processing, FPGA sends event and warning data signals to buzzer and led signaling circuitry. These LEDs and buzzer states the status of another vehicle whether another vehicle is taking turn or hitting brake or taking no action. Similarly, FPGA also generates 8 bit voice command data. This data is generated after processing real time scenarios of vehicles such as relative position, heading, vehicular operations, and speed context. This data is sent to microcontroller1 and finally this microcontroller1 transmits this data to DFPlayer to announce the vehicular scenarios by voice to the driver. Information, Voice command, Event signals and warning signals are generated. Emergency, Blind spot, Forward collision and Intersection warning scenarios are considered.

Measurement of Bearing

Bearing is angle measured with respect to magnetic north to the line joining current position of this vehicle to current position of another vehicle. It is determined with the help of GPS coordinates.

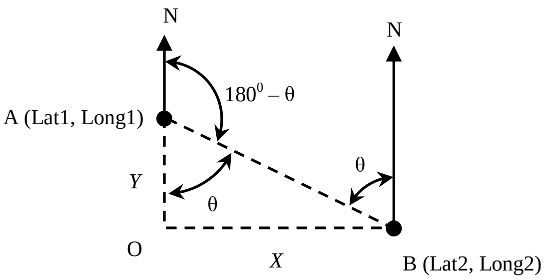


Fig. 2 Determination of bearing

Bearing, $\theta = Tan - 1(X/Y)$ (1)

Lat1 = Latitude of A, Lat2 = Latitude of B

Long1 = Longitude of A, Long2 = Longitude of B

$X = cos\,(Lat2) * sin\,(\Delta Long)$ (2)

$Y = \cos(Lat1) * \sin(Lat2) - \sin(Lat1) * \cos(Lat2) * \cos(\Delta Long)$ (3)

Distance between A and B by Haversine formula:

$d = R * c$ (4)

where, R = Radius of earth

$c = 2.atan2\,(\sqrt{a}, \sqrt{(1 - a)})$ (5)

$a = sin2\,(\Delta Lat/2) + cos\,Lat1 * cos\,Lat2 * sin2(\Delta Long/2)$ (6)

Measurement of Heading

Heading gives the direction of motion of object. Heading is determined according true north by correcting using magnetic declination. Heading(θ) is measured as:

$\theta = atan2\ (m_y, m_x)$

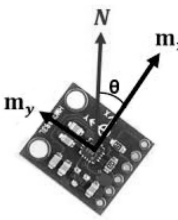


Fig. 3 Determination of Heading

CASE I

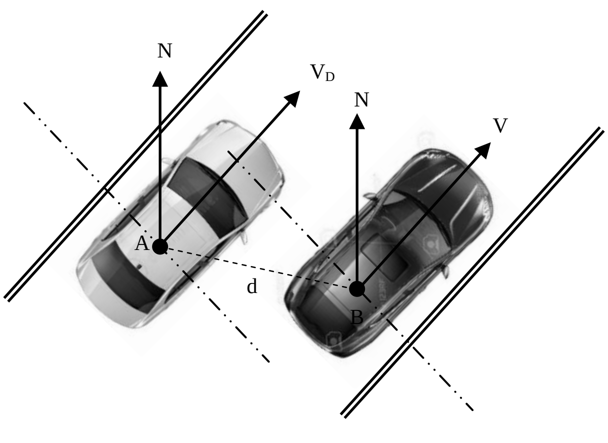


Fig. 4 Relative position between vehicles A and B

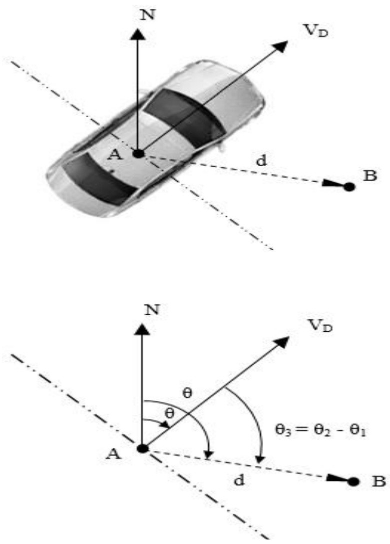


Fig. 5 Relative position of vehicle B (respect to A)

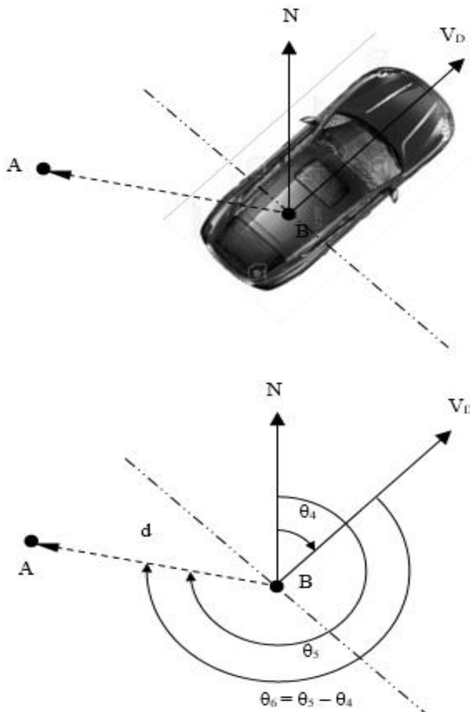


Fig.6 Relative position of vehicle A (respect to B)

Where, N = Magnetic north

VD = Vehicle Direction

d = Distance between to vehicles

A= GPS Position of vehicle A

B = GPS Position of vehicle B

θ1 = Heading of vehicle A (compass reading)

θ2 = Bearing between P and Q with respect to N

θ3 = θ2 – θ1 = location of B with respect to VD of A

θ4 = Heading of vehicle B (Compass reading)

θ5 = Bearing between P and Q with respect to N

θ6 = θ5 – θ4 = location of vehicle A with respect to VD of vehicle B

CASE II

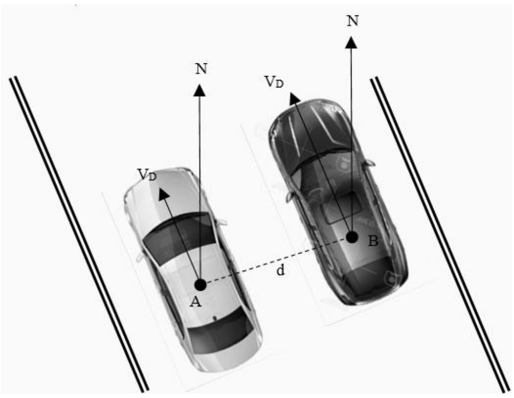


Fig. 7 Relative position between vehicles A and B

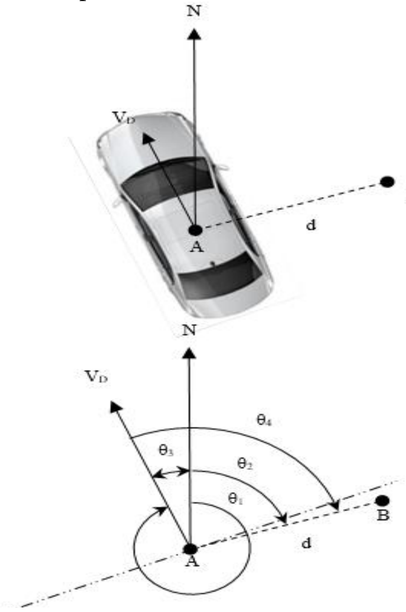


Fig. 8 Relative position of vehicle B (respect to A)

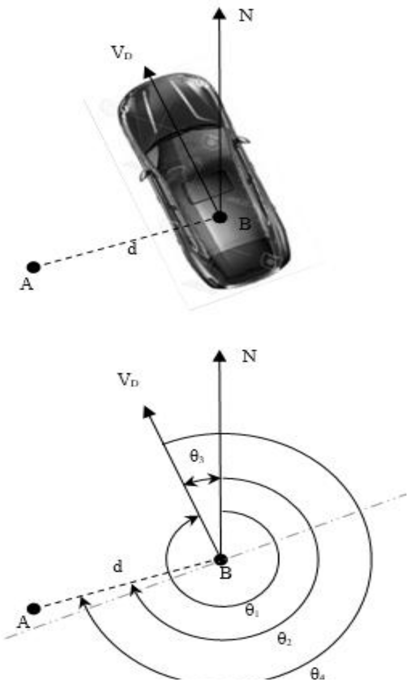


Fig. 9 Relative position of vehicle A(respect to B)

θ_1 = Heading of vehicle A (Compass reading)
θ_2 = Bearing between A and B with respect to N
θ_3 = 3600 – θ_1
θ_4 =θ_3–θ_2=Location of vehicle B with respect to VD

Positions are 8 bit coded and then transmitted to FPGA. It is depicted as following:

Table 1: Binary coding of relative position

Position	8 bit binary code
Front	00000001
Right Corner	00000010
Right Side	00000011
Right Blind Spot	00000100
Behind	00000101
Left Blind Spot	00000110
Left Side	00000111
Left Corner	00001000

The heading difference (HD) is determined in clockwise direction and is also coded in 8 bit form and transmitted to FPGA. There are four possible heading differences, i.e. 0, 90, 180 and 270. This heading difference has its meaning. The HD 0 means both vehicles are moving same direction. HD 180 means vehicles are approaching to each other from opposite direction. HD 90 means vehicles are approaching to intersection from left side while HD 270 states vehicles are approaching to intersection from right side. If VDA and VDB be the heading of vehicle A and B respectively, then following cases considered before determining relative heading;

Case 1: Relative heading, as seen from vehicle A
Condition 1: VDA> VDB; HD = 3600 –VDA + VDB
Condition 2: VDA< VDB; HD = VDB – VDA
Case 2: Relative heading, as seen from vehicle B
Condition 1: VDB> VDA;HD = 3600 – VDB + VDA
Condition 2: VDB< VDA;HD = VDA – VDB

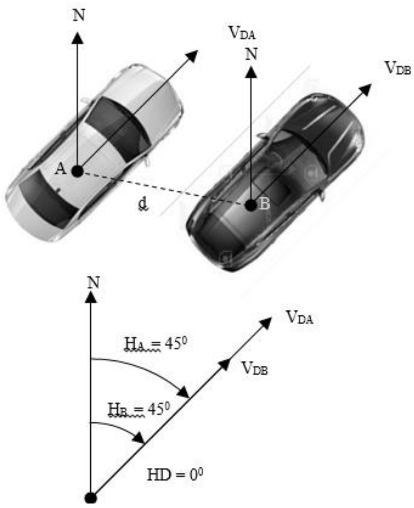


Fig. 10 Determination of heading difference

The net heading as seen from both vehicles to each other = 450 – 450

HD = 0

That is, vehicles are moving in same direction

Scenario 2

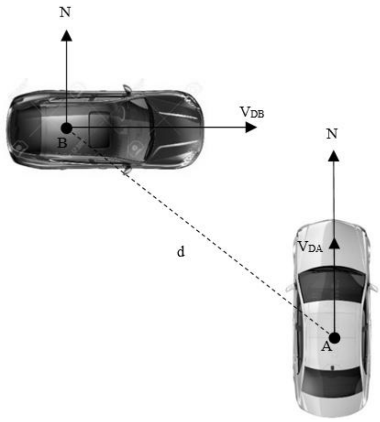


Fig. 11 Determination of HD at intersection

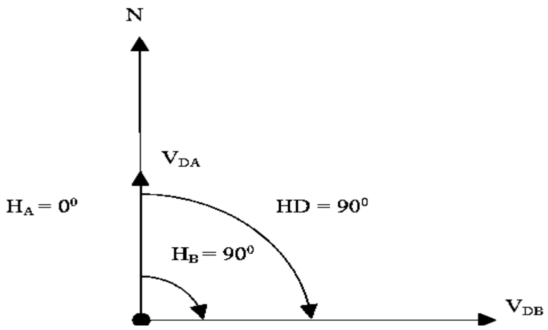


Fig. 12 Equivalent diagram of determination of HD at intersection seen from vehicle A

The net heading (seen from vehicle A in clockwise direction) = 900 – 00 = 900

HD = 900

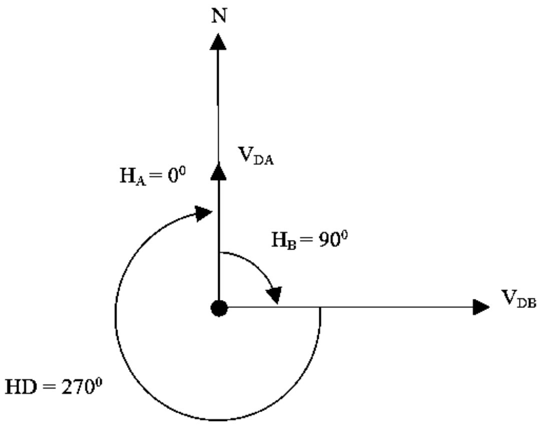


Fig. 13 Equivalent diagram of determination of HD at intersection seen from vehicle B

The net heading (seen from vehicle B in clockwise direction) = 3600 – 900 – 00 = 2700 = HD

i.e, vehicle A is approaching intersection from right

Scenario 3

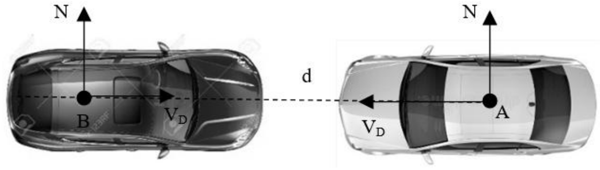


Fig. 14 Determination of HD when vehicles are approaching to each other

HD (from A in clockwise) =3600–2700 + 900 = 1800

HD (seen from B in clockwise) = 270 0 – 900 = 1800

Heading difference is transmitted to FPGA in coded form as shown in table.

Table 2: Binary coding of HD

Dec	8 bit binary number		Description
	HD	DR	
140	1000	1100	HD 0 ;same direction within Distance Range (DR)
172	1010	1100	HD 90;approaching intersection from left within DR
188	1011	1100	HD 180;approaching from opposite within DR
236	1110	1100	HD 270;approaching intersection from right within DR
131	1000	0011	HD 0;same direction not within DR
163	1010	0011	HD 90;approaching intersection from left not within DR
179	1011	0011	HD 180;approaching from opposite not within DR
227	1110	0011	HD 270;approaching intersection from right not within DR

3. Result and Discussion

3.1. FPGA Implementation

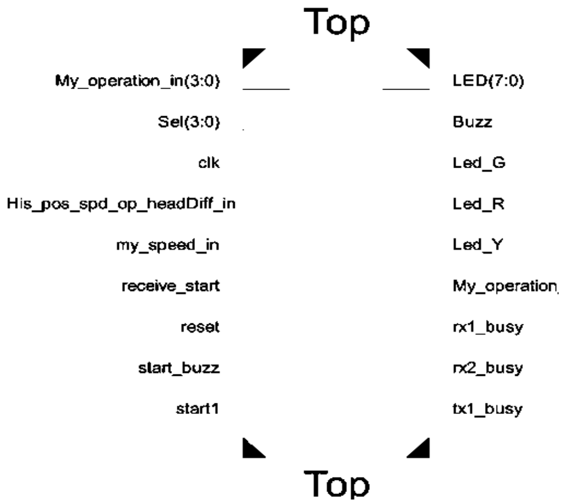


Fig. 15 Schematic of Top Module

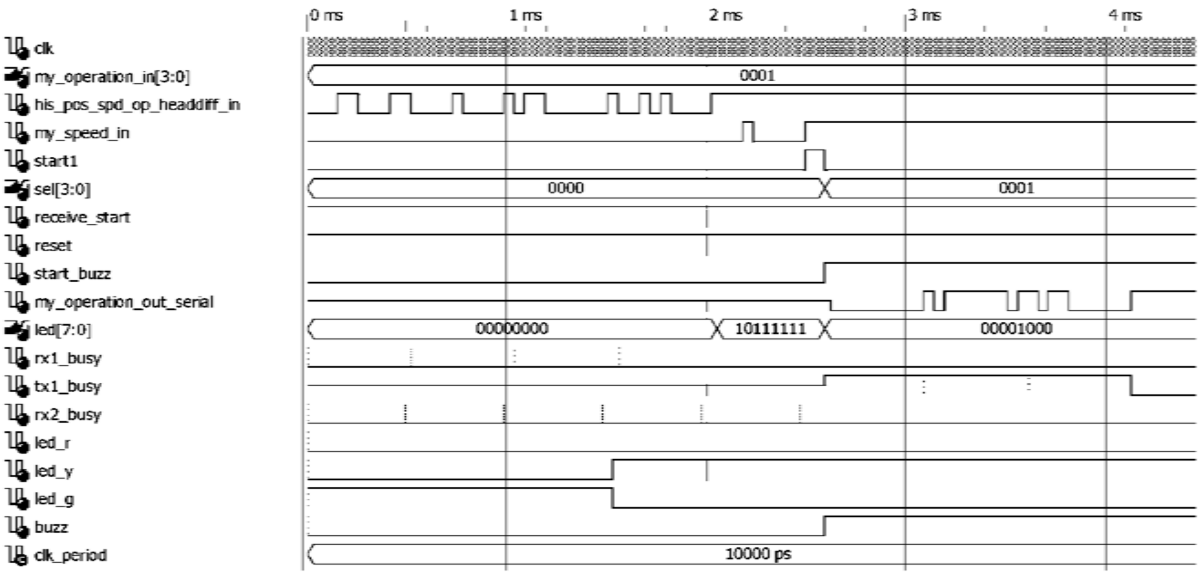


Fig. 16 Simulation output of Top module

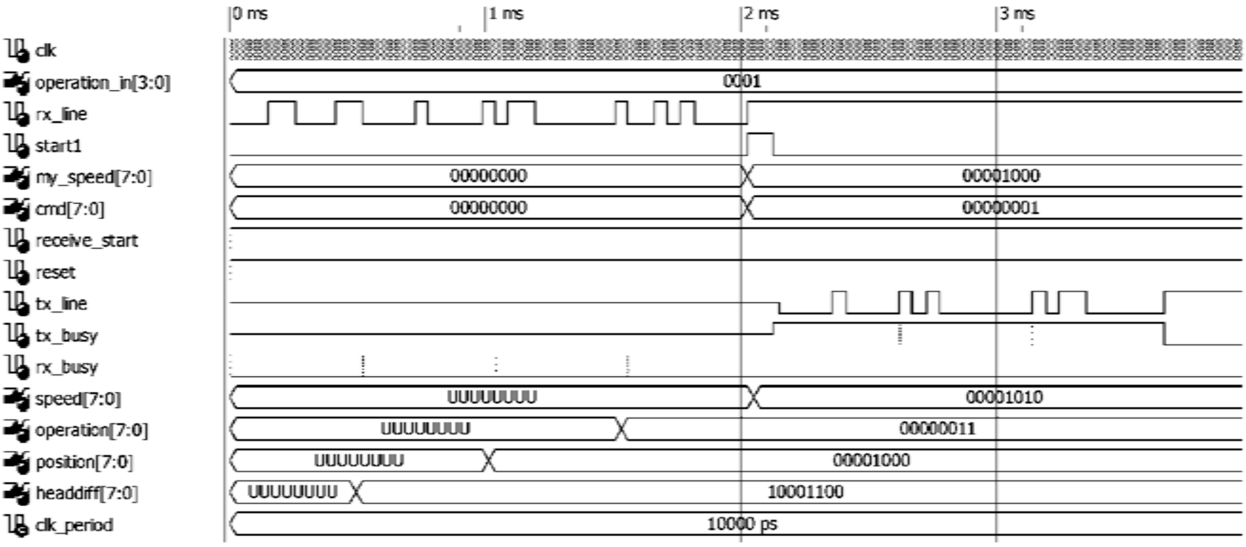


Fig. 17 Simulation output of Module 1

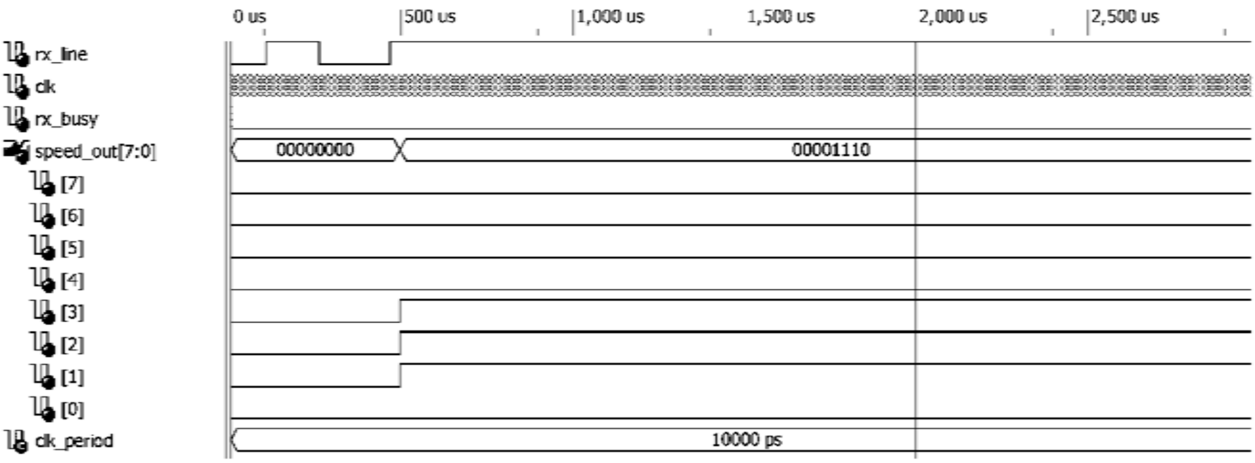


Fig. 18 Simulation output of Module 2

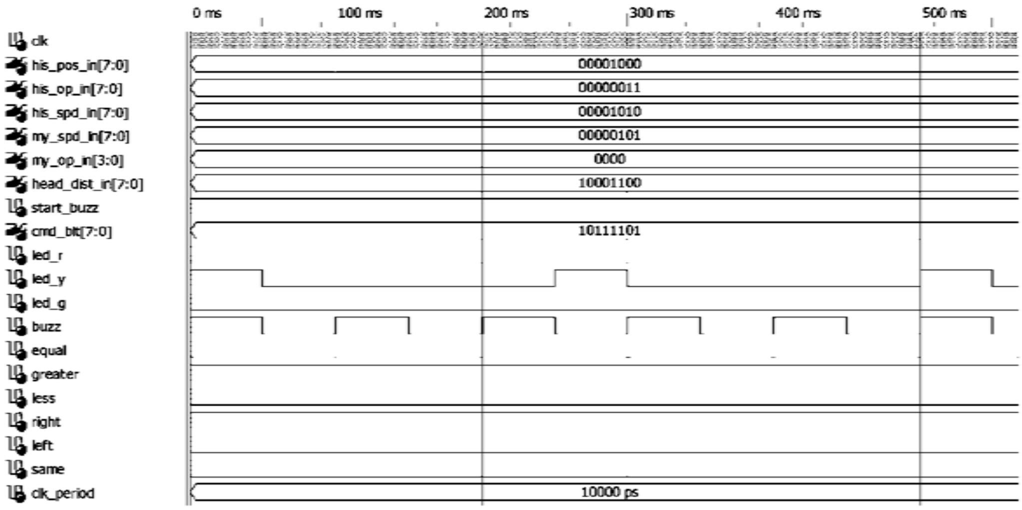
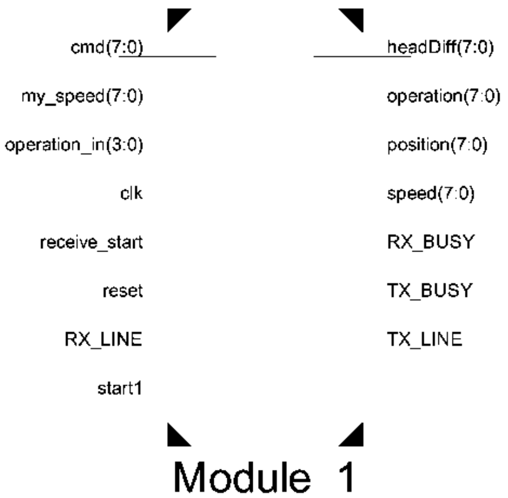
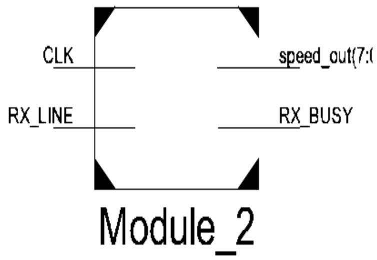


Fig. 19 Simulation output of Module 2





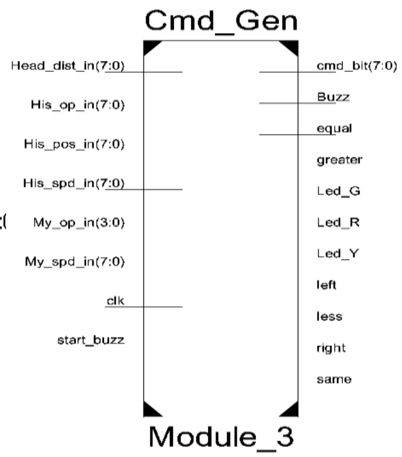


Fig. 20 Schematic of Modules 1 Fig.21 Schematic of Module 2 Fig. 22 Schematic of Modules3

3.2 Hardware Implementation

```
Lt1 = 27.673946  Lg1 = 85.407096
Lt2 = 27.673950  Lg2 = 85.407173
D = 7.99 m  B = 87.15  PA = 6.15  H = 81.00 Spd =5  R_H = 80.00  HD = 140, 10001100 R_Spd =0.00  RX_Op =0.00 F =0  2:RC

Lt1 = 27.673946  Lg1 = 85.407096
Lt2 = 27.673950  Lg2 = 85.407173
D = 7.99 m  B = 87.15  PA = 6.15  H = 81.00 Spd =5  R_H = 80.00  HD = 140, 10001100 R_Spd =0.00  RX_Op =0.00 F =0  2:RC

Lt1 = 27.673946  Lg1 = 85.407096
Lt2 = 27.673950  Lg2 = 85.407173
D = 7.99 m  B = 87.15  PA = 6.15  H = 81.00 Spd =5  R_H = 80.00  HD = 140, 10001100 R_Spd =0.00  RX_Op =0.00 F =0  2:RC
```

Fig. 23 Serial monitor output and vehicles PositionMap, vehicle B at right corner moving towards same direction

```
Lt1 = 27.673915  Lg1 = 85.407112
Lt2 = 27.673936  Lg2 = 85.407066
D = 5.33 m  B = 296.78  PA = 216.78  H = 80.00 Spd =4  R_H = 72.00  HD = 140, 10001100 R_Spd =0.00  RX_Op =0.00 F =0  6:LBS

Lt1 = 27.673915  Lg1 = 85.407112
Lt2 = 27.673936  Lg2 = 85.407066
D = 5.33 m  B = 296.78  PA = 216.78  H = 80.00 Spd =4  R_H = 72.00  HD = 140, 10001100 R_Spd =0.00  RX_Op =0.00 F =0  6:LBS

Lt1 = 27.673915  Lg1 = 85.407112
Lt2 = 27.673936  Lg2 = 85.407066
D = 5.33 m  B = 296.78  PA = 216.78  H = 80.00 Spd =4  R_H = 72.00  HD = 140, 10001100 R_Spd =0.00  RX_Op =0.00 F =0  6:LBS
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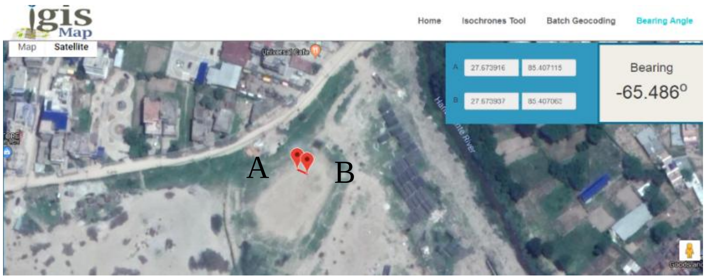

Fig. 24 Serial Monitor Output and Position Map when vehicle B at blind spot moving towards same direction

```
Lt1 = 27.673934  Lg1 = 85.407096
Lt2 = 27.673944  Lg2 = 85.407173
D = 8.05 m  B = 82.84  PA = 8.84  H = 74.00 Spd =3  R_H = 349.00  HD = 236, 11101100 R_Spd =0.00  RX_Op =0.00 F =0  2:RC

Lt1 = 27.673934  Lg1 = 85.407096
Lt2 = 27.673944  Lg2 = 85.407173
D = 8.05 m  B = 82.84  PA = 8.84  H = 74.00 Spd =3  R_H = 349.00  HD = 236, 11101100 R_Spd =0.00  RX_Op =0.00 F =0  2:RC

Lt1 = 27.673934  Lg1 = 85.407096
Lt2 = 27.673944  Lg2 = 85.407173
D = 8.05 m  B = 82.84  PA = 8.84  H = 74.00 Spd =3  R_H = 349.00  HD = 236, 11101100 R_Spd =0.00  RX_Op =0.00 F =0  2:RC

Lt1 = 27.673934  Lg1 = 85.407096
Lt2 = 27.673944  Lg2 = 85.407173
D = 8.05 m  B = 82.84  PA = 8.84  H = 74.00 Spd =3  R_H = 349.00  HD = 236, 11101100 R_Spd =0.00  RX_Op =0.00 F =0  2:RC
```

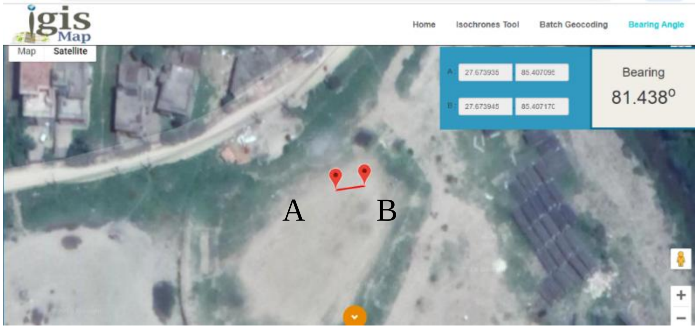

Fig. 25 Serial Monitor Output and Position Map when vehicle B at left blind spot moving opposite direction

```
Lt1 = 27.673900  Lg1 = 85.407089
Lt2 = 27.673933  Lg2 = 85.407150
D = 7.33 m  B = 60.41  PA = 1.41  H = 59.00 Spd =0  R_H = 65.00  HD = 140, 10001100 R_Spd =0.00  RX_Op =12.00 F =0  2:RC

Lt1 = 27.673900  Lg1 = 85.407089
Lt2 = 27.673933  Lg2 = 85.407150
D = 7.33 m  B = 60.41  PA = 1.41  H = 59.00 Spd =0  R_H = 65.00  HD = 140, 10001100 R_Spd =0.00  RX_Op =12.00 F =0  2:RC

Lt1 = 27.673900  Lg1 = 85.407089
Lt2 = 27.673933  Lg2 = 85.407150
D = 7.33 m  B = 60.41  PA = 1.41  H = 59.00 Spd =0  R_H = 65.00  HD = 140, 10001100 R_Spd =0.00  RX_Op =12.00 F =0  2:RC

Lt1 = 27.673900  Lg1 = 85.407089
Lt2 = 27.673933  Lg2 = 85.407150
D = 7.33 m  B = 60.41  PA = 1.41  H = 59.00 Spd =0  R_H = 65.00  HD = 140, 10001100 R_Spd =0.00  RX_Op =12.00 F =0  2:RC
```

Fig. 26 Serial Monitor Output and Position Map when vehicle B at right corner coming towards the lane

Table 3: Device utilization summary

Device Utilization Summary (estimated values)			
Logic Utilization	Used	Available	Utilization
Number of Slices	62	4656	1%
Number of Flip Flops	27	9312	0%
Number of 4 input LUTs	119	9312	1%
Number of bonded IOBs	6	232	2%
Number of GCLKs	1	24	4%

For first vehicle with latitude of 27.673946 and longitude of 85.407096 and second vehicle with latitude of 27.673950 and longitude of 85.407173, distance between two vehicles is found to be 7.99m with bearing value 87.15º, relative position angle of 6.15º, heading of first vehicle to be 81º and speed of 5 kmph, heading of second vehicle to be 80º at rest which means the second vehicle is detected to be located at right corner of first vehicle. Here first vehicle is moving at same direction with respect to second vehicle. For first vehicle with latitude of 27.673915 and longitude of 85.407112 and second vehicle with latitude of 27.673936 and longitude of 85.407066, distance between two vehicles is found to be 5.33m with bearing value 296.78º, relative position angle of 216.78º, heading of first vehicle to be 80º and speed of 4 kmph, heading of second vehicle to be 72º at rest which means the second vehicle is detected to be located at left blind spot of first vehicle. So, here first vehicle is moving at same direction with respect to second vehicle.

For first vehicle with latitude of 27.673917 and longitude of 85.407119 and second vehicle with latitude of 27.673961 and longitude of 85.407127, distance between two vehicles is found to be 4.94m with bearing value 8.66º, relative position angle of 276.66º, heading of first vehicle to be 92º and speed of 3 kmph, heading of second vehicle to be 83º at rest which means the second vehicle is detected to be located at left corner of first vehicle. So, here first vehicle is moving at same direction with respect to second vehicle. For first vehicle with latitude of 27.673934 and longitude of 85.407096 and second vehicle with latitude of 27.673944 and longitude of 85.407173, distance between two vehicles is found to be 8.05m with bearing value 82.84º, relative position angle of 8.84º, heading of first vehicle to be 74º and speed of 3 kmph, heading of second vehicle to be 349º at rest which means the second vehicle is detected to be located at right corner of first vehicle. So, here first vehicle is moving in intersecting direction with respect to second vehicle.

4. Conclusion

Vehicle communication has been successfully implemented for the mentioned scenarios. FPGA processes the data and communication signals in real-time environment. Hence, this technology can prevent unfortunate accidents due to blind spots in real world. It is value addition in safety feature in the vehicles. It is also applicable in self-driving vehicles.

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