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DESIGN AND IMPLEMENTATION OF V2X SYSTEM FOR THE AUTONOMOUS VEHICLE USING FPGA

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ABSTRACT

This paper presents the implementation of vehicle-to-everything (V2X) communication on an autonomous vehicle. The V2X system consists of a set of traffic lights for crossroad, cars and a road side unit (RSU) whereas the autonomous vehicle consists of an input data management system and controller for automated driving. In this project, we focus on connecting the vehicle to the network and utilizing the connectivity for non-critical message transmission. A mesh network is formed using star topology. The security of the mesh network is then enhanced with a mesh network password. Function of the RSU is to connect and act as a central unit that command the traffic light and other nodes of the network. RSU is the only unit with the authority to give commands to infrastructure of the network, for example, the traffic light. Under normal condition, the traffic light will act based on preset setting. With input from pedestrian through android application, or emergency request from autonomous vehicle, the RSU will give command and issue the traffic light to change the state.

Keywords: V2X system, autonomous vehicle, FPGA design.

INTRODUCTION

Vehicle-to-everything (V2X) communication is the passing of information from a vehicle to any entity that may affect the vehicle, and vice versa. It is a vehicular communication system that incorporates other more specific types of communication as V2I(vehicle to infrastructure), V2V(vehicle to vehicle), V2P(vehicle to pedestrian), and V2D(vehicle to device)[1]. Whereas an autonomous vehicle is known as an intelligent control system that are able to navigate by itself [2].

V2X system and autonomous vehicle is the solution to road accident, which is mostly caused by human error. To address this problem, vehicle, pedestrian, and infrastructure such as road side unit and traffic light will connect to the V2X network to obtain relevant data for road traffic application. Main objective of the application is to decrease the number of death toll and injured, and increase road traffic efficiency.

The crucial design of autonomous vehicle is implemented using VHDL (VHSIC Hardware Descriptive Language) to utilize the processing power and parallelism of Field Programmable Gate-Array. A vehicular network consists of 1. autonomous vehicle, 2. roadside unit (RSU), 3. traffic light, and 4. pedestrian will be formed and applications will be deployed under the network.

Applications deployed using V2X system are 1. collision warning & emergency braking system, 2. propagation of data from one vehicle from another using WiFi ad-hoc network, and 3. signal phase and timing (SPAT) of traffic light. The autonomous vehicle will be designed so that the vehicle will react, issue warning, halt vehicle or display data obtained automatically without human input or assistant.

CONCEPT OF V2X SYSTEM & AUTONOMOUS VEHICLE)

Vehicle-to-everything (V2X) communication is the passing of information from a vehicle to any entity that may affect the vehicle, and vice versa. It is a vehicular communication system that incorporates other more specific types of communication as V2I(vehicle to infrastructure), V2V(vehicle to vehicle), V2P(vehicle to pedestrian), and V2D(vehicle to device)[1]. Whereas an autonomous vehicle is known as an intelligent control system that are able to navigate by itself [2].

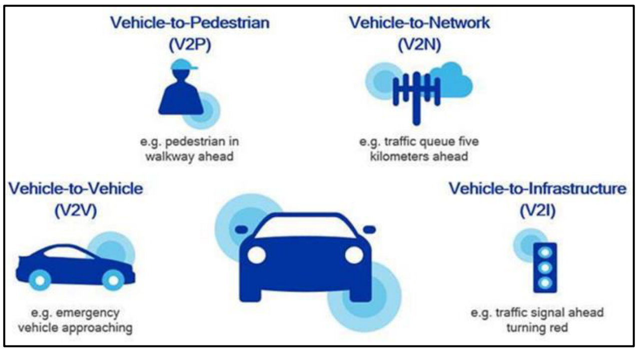

Figure-1. Examples of connections and applications [5].

Figure-1 illustrates the examples of connection and application can be achieved through V2X system. Vehicle-to-pedestrian, vehicle-to-network, vehicle-to-infrastructure and vehicle-to-vehicle are types of V2X system. The applications showed for each types of connection are achievable and realistic to be deployed in complex traffic.

Summarizing scholarly journals and articles to explore possibilities of V2X, application can developed for

a) Active road safety purpose,
b) Managing traffic flow,
c) Info broadcast applications and
d) Motion control of vehicle [6-11].

Some examples of type 1 applications are collision warning, assistance on lane changing, and pre-crash sensing. Other than this, vehicles on the road may detect traffic changes and notify nodes on the network, for example, vehicles and roadside unit. Primary aim of this type of application is to decrease probability of traffic accidents and to prevent injury or death.

Type 2 application aims to improve traffic flow. This system is hoped to ease traffic congestion. Information such as maps, traffic light condition and relevant message will be updated to vehicle on the network. It includes speed management and co-operative navigation on the vehicle. Signal phase and timing (SPAT) is classified as a type 2 application

Broadcasting of info includes notification on requested data and media downloading. Furthermore, this types of application also provide the possibility for global internet services which extends the connection for insurance, financial, fleet management and parking zone management. The data could be sent and integrated with autonomous vehicle to autopark with appropriate parking space while the passenger relaxes.

The authors in [8] describe motion control as applications that issue operator warnings or regulate local vehicle actuators to ensure safe and/or efficient operation. For example, aircraft may use a direct route of travel. Differ from current "air highway" system, each aircraft would avoid collision by determine its path of trajectory to a destination itself. We may send alert to crew if a protection zone is invaded. The communication is expected to optimize path planning of vehicles.

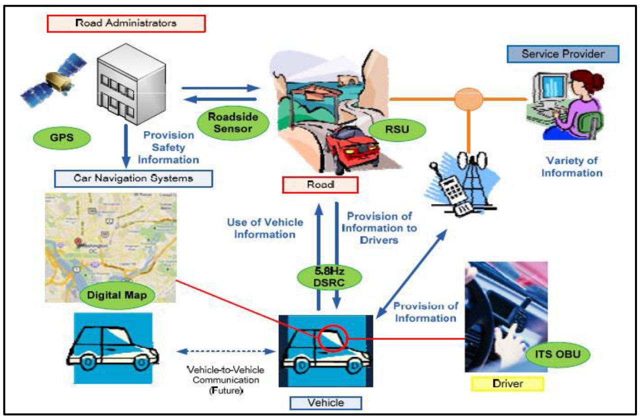

Figure-2. Smartway architecture: positioning, mapping and communication [7].

Figure-2 illustrates the Intelligent Transport System (ITS) for positioning, mapping and communication. OBU is the abbreviation for On-Board Unit, where the unit is embedded to act as communication device for the vehicle.

In the context of this project, the autonomous vehicle will be implemented via ground vehicle. Although advancement of autonomous aerial and underwater vehicle is under research and development academically, ground autonomous vehicle has been the focus of research to produce commercial product.

In 2013, a classification system of levels of driving automation is released by the National Highway Traffic of United States, from SAE level of 0, meaning requires no automation to level 5, meaning the vehicle had achiFrom the Table-1, level of automation we try to achieve is level 2, where steering, speed and acceleration of the vehicle is controlled by human. SAE International levels of autonomous is useful while the state and federal government to enforce legislatures law while commercial party can make use of the levels to determine and design various aspect of the autonomous vehicle.

Implementation of autonomous vehicle is said to improve the safety and efficiency of transportation. Other than this, mobility of a particular person is increased. For example, the autonomous vehicle is able to transport a blind person with hardship in to travel in the world without the obvious capability to visually inspect their surrounding. The new autonomous vehicle is believed to reduce the environment and energy impacts too.

We know from airbags that if a framework is created which spares many lives however causes a few cases of death, the death won't be accepted. Spacing of the vehicles is the primary line of defense. Utilizing this knowledge, the designed eved full automation.autonomous vehicle should be extremelly careful while cruise controlling the speed and steering of the vehicle.

One of the practical scenario is that a larger lorry is blocking the view of smaller vehicle in a narrow road. Through V2X system, view in front of the lorry may be transmitted to the smaller vehicle so the autonomous system may utilize the data while making cruise control decision. As a conclusion, by combining both V2X system and the autonomous system, we implement an intelligent transport system on the road. The autonomous system will make practical and effect use of data obtained through V2X system in navigation of the road to reach destination.

Table-1.SAE levels and its associate definition [12].

Level 0	**No automation**	**The driving is completely done by human without assistantfrom system of vehicle**
Level 1	Driver assistance	Either of speed, acceleration or steering controlled byautonomous vehicle, remaining will be controlled by human.
Level 2	Partial Automation	Speed, acceleration and steering controlled by autonomousvehicle, remaining controlled by human.
Level 3	Conditional Automation	Driving is done by the autonomous vehicle. Human willmonitor and intervene if necessary.
Level 4	High Automation	Driving is done by the autonomous vehicle although humanfail to intervene.
Level 5	Full Automation	Driving is completely done by the vehicle itself in all kind of environments and conditions.

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VEHICULAR NETWORKING ANDAUTONOMOUS VEHICLE PROJECTS AROUND THE GLOBE

Summarizing the last decade work, where most was on overcome specific challenges, including technological challenges and laws and regulation of V2X communication in clearly targeted research projects, it now shifts towards “real-world” testing in field operational tests. The purpose of these field operational tests is to investigate problems that have not been properly addressed in the research phase. These questions involved topics such as scalability of the network. Other than this, the effectiveness of application during real world deployment is vital on improving the traffic safety application [13-15].

Real world deployment projects can be observed geographically. Projects carried out in Japan includes ETC (Electronic Toll Collection). This infrastructure is implemented and other infrastructures for vehicle safety communications is constantly rollout for public interest. The spread of ETC has decreased congestion by half, even though traffic volume has increased. The ETC utilization rate increased from 2% at April 2002 to 20% at April 2004 [16]. Examples of other ITS infrastructures are Smartway and VISC onboard units.

In EU and USA, primary aim to these projects focus on standardization of V2X communications. While these projects are mainly carried out by industry, governments are involved and provide aid as well. One of the most important efforts is C2C-CC, the car-to-car consortium.

Other efforts such as ARIB (Association of Radio Industries and Businesses), ISO (International Organization for Standardization), ETSI (European Telecommunications Standards Institute) and HIGHTS (High precision positioning for cooperative ITS) also contributed to the development of V2X communication. Some other supportive action of European Union includes funding of AdaptIVe (Automated Driving Applications &Technologies for Intelligent Vehicle), CODECS (Cooperative ITS Deployment Coordination Support), COPASS4D, MAVEN (Managing Automated Vehicles Enhances Network), and ROADART (Research On Alternative Diversity Aspects for Trucks) [17].

The most important aspect of standardization projects is the formation of IEEE 802.11p technology by IEEE worktask. This technology is mainly used to define the data link technology for various on-road applications.

It defines the specification of On-Board Unit for MAC and PHY layer [18].

Research of autonomous vehicle has been underway constantly. The most media attracting project is the Waymo project by Google Inc. The Firefly model had been drove on complex city streets for more than 3 millions miles. The project is proved to be successful. In 2017, the Firefly retired and is replaced by the Chrysler Pacifica Hybrid minivans.

Figure-3. Firefly of Waymo project. [36]

Figure-4. The fully self-driving Chrysler Pacifica Hybrid minivans. [36]

Some features of the Chrysler Pacifica Hybrid Minivans include Uconnect® systems which provides real-time traffic, weather updates, sports scores, fuel prices and more. It also includes a mobile app to view driving history report, vehicle charging progress, to locate a charging station and more. Important features of this autonomous vehicle includes 360° SURROUND VIEW CAMERA with four camera positioned around the vehicle to create a fully stiches image, full-speed forward collision warning plus with Automated Emergency Braking (AEB) system, parking assistance and rear park asisst with cross path detection.

Remarkably, the 2018 Myvi by Perodua, Malaysia's largest car manufacturer also includes features such as pre-collision warning, pre-collision braking, front-departure alert and pedal misoperation control. However, the features is only included in the Myvi 1.5L AV-Automatic version.

Other autonomous vehicles developed include models from Tesla, GM, Mercedes, Volvo, BMW, Uber, Ford, and Nissan. These semi-autonomous vehicles have reach SAE level 2. In USA, 21 states pass the law to permit driverless car to drive on the road. This legalisation will promote the use of driverless car although the price of early adaptation is high.

ARCHITECTURE, PROTOCOL ANDSTANDARDIZATION OF VEHICULAR NETWORKING

IEEE Task Group p is tasked to develop an amendment named IEEE 802.11p to the 802.11 standard. The standard comprise of specification of layer 3 and layer 4 of V2X network [19]. Standards included are IEEE 1609.1-resource manager, IEEE 1609.2-security, IEEE 1609.3-networking, and IEEE 1609.4-multichannel operation. The combination of IEEE 802.11p and the IEEE 1609 protocol suite is denoted as WAVE (Wireless Access in Vehicular Environments) [18,20,21,22].

Several recommendation made for V2X communication:

a) Communications: Radio communication needs to be refined and should includes extent such as strength of signal, bilateral IP-based transaction with UDP, and logic design of services, application management and arbitration of competing services from nearby access provider.

b) Positioning: Localization of a vehicle is needed. However, while the functionality is required, we need to consider the cost of implementation. Hence, the provisioning of this functionality should not be prescribed, but act as an additional feature for enhancement. Furthermore, to improve the accuracy and availability of localization in all environments, investigation should be carried out.

c)Security: The project shows that the basic security functions can be implemented and work in the context of the system. Aspect to be added to the security system could be anonymous signing scheme and data signing and verification. The data signing and verification strategy for the fast transmitting messages, should be balanced between the importance of security and data throughput.

d) Advisory Message Delivery Services (AMDS): It is recommend that to design and implement the AMDS where it could be more easy to use. Although the system is understand to perform excellently during the test, such improvement is needed to enhance the communication [23-25].

From the recommendation above, we can summarize that

a) Maximum latency shall not exceed 100 ms for traffic safety application,
b) Frequency of generation of 10 messages per second,
c) Minimum range of the communication should not be less than 150 meters

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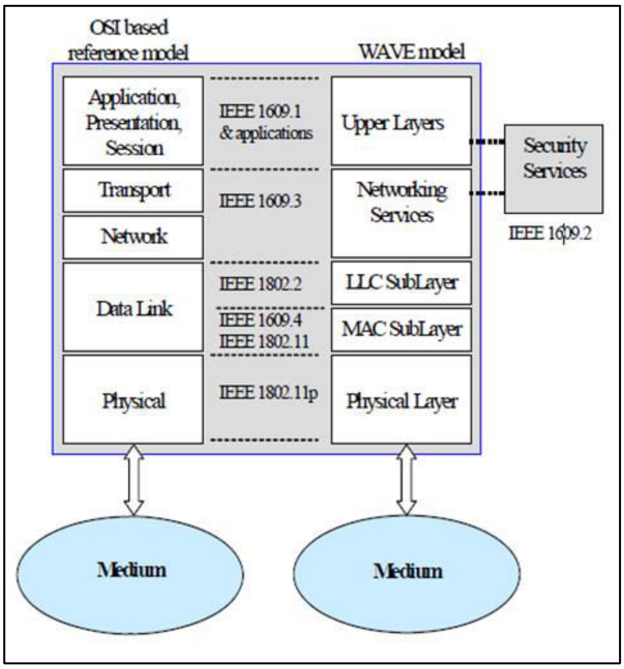

Figure-5. WAVE protocol suite [20].

Su *et al.*[26] proposed a substitution of WAVE with Wi-Fi Network. During the implementation of V2X system, equipment and hardware based on 802.11p, which had been officially standardized by IEEE, is required. However, there is no common DSRC standard exist in this point. The proposed solution can act as a temporary solution where to be replaced by WAVE/DSRC OBU in the future.

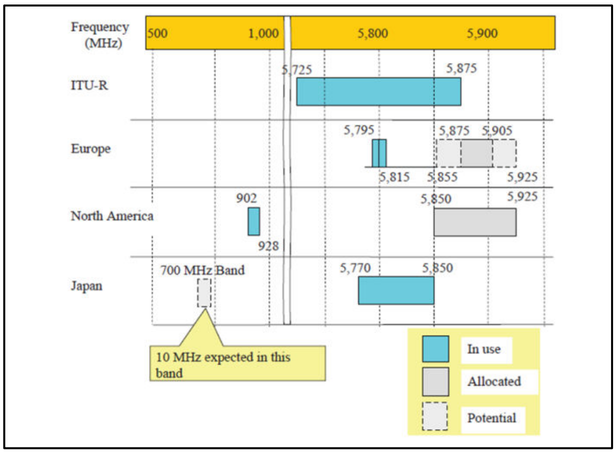

Figure-6. DSRC frequency band specifications in Europe, North America and Japan. [20].

As observed from the Fig 6, The ITU Radiocommunication Sector uses 5725- 5875 Mhz band for DSRC, where Europe uses 5795 - 5815 Mhz band, 902 - 928 Mhz for North America and Japan uses 5770 - 5850 Mhz.

WiFi is defined in the 802.11 family. In this project, 802.11 b/g/n/e/iWiFisuite is used and supported. Hence, the vehicle can connect to any of the V2X node with protocol suite supported above. In this project, we try to implement WiFi in a way such that it satisfies requirement of V2X communication, for example low latency for transmission of critical message such as traffic safety message.

IEEE 802.11b standard was released on September 1999. This standard provides 11 Mbps transmission (with a fallback to 5.5, 2 and 1 Mbps) in the 2.4 GHz operating frequency and bandwidth of 22MHz. The 802.11b uses only DSSS (Direct Sequence Spread Spectrum) modulation technique. This standard also employs the SISO antenna technology as in the IEEE802.11a standard. The IEEE802.11b standard was ratified on 1999 from the original IEEE802.11 standard which allowed wireless functionality comparable to Ethernet. The IEEE802.11b standard is prone to higher interference due to the fact that the 2.4GHz frequency range is becoming crowded with carriers, hence increased interference risk. The indoor and outdoor ranges for this standard is 35m to 140m.

The standard 802.11g was released in 2003 as an IEEE specification for WiFi and it can take up to potential bandwidth of 54Mbps while 802.11b only support up to 11Mbps. 802.11g uses OFDM or DSSS modulation and implement SISO.Its range are from 38m to 140m.

The 802.11n standard was approved in 2009 and it uses different remote antenna to send and get data. Orthogonal frequency-division multiplexing (OF modulation is applied in the IEEE802.11n standard. This innovation utilized with the IEEE802.11n standard is known as Multiple Input, Multiple Output (MIMO). It refers to the capacity of 802.11n and similar technology to manage several synchronous radio signals. The MIMO increments both the range and throughput of a remote system. An extra procedure utilized by 802.11n includes expanding the channel transfer speed from 20MHz to 40MHz. The 802.11n standard is believed to support to transmission speed up to 300 Mbps. The IEEE802.11n indoor/outside range are 75m, and 250m separately.

802.11e is the QoS for wireless multimedia technology. The 802.11e enhances the Distributed Coordination Function (DCF) and the Point Coordination Function (PCF), through a new coordination function: the hybrid coordination function (HCF). Within the HCF, there are two methods of channel accessed, similar to those defined in the legacy 802.11 MAC: HCF Controlled Channel Access (HCCA) and Enhanced Distributed Channel Access (EDCA). Both EDCA and HCCA define Traffic Categories (TC). For example, emails could be assigned to a low priority class, and Voice over Wireless LAN (VoWLAN) could be assigned to a high priority class.

802.11i is released for the purpose of WiFi Protected Access II (WPA2). This standard specifies security mechanisms for wireless networks, replacing the short Authentication and privacy clause of the original standard with a detailed Security clause [27].

Autonomous vehicle with FPGA

An important feature of Field Programmable Gate Array (FPGA) is the capability to parallelly process and execute in lower level of architecture circuits. FPGA is extremely suitable for computationally intensive applications. Hence, in our case, when delay is not allowed in processing traffic safety related message, FPGA is the most suitable choice for implementation.

Several autonomous vehicles related research is carried out. One of the project carried out in FPGA platform are work by Kim *et al*. [2]. They had proved the feasibility using FPGA as the autonomous control platform. The authors show the utilization of FPGA for the outline of a minimized continuous control framework on a self-navigate vehicle, which comprises of a routing functional block, vehicle control functional block and teleoperation functional block.

Figure-9 demonstrates the control system of autonomous vehicle designed by Kim et al. Stereo camera, IMU, GPS, range sensor, rotary encoder and DC motor is deployed in this project. The real-time system also uses wireless communication to get real time video feedback, remote control and status of vehicle. The control system.

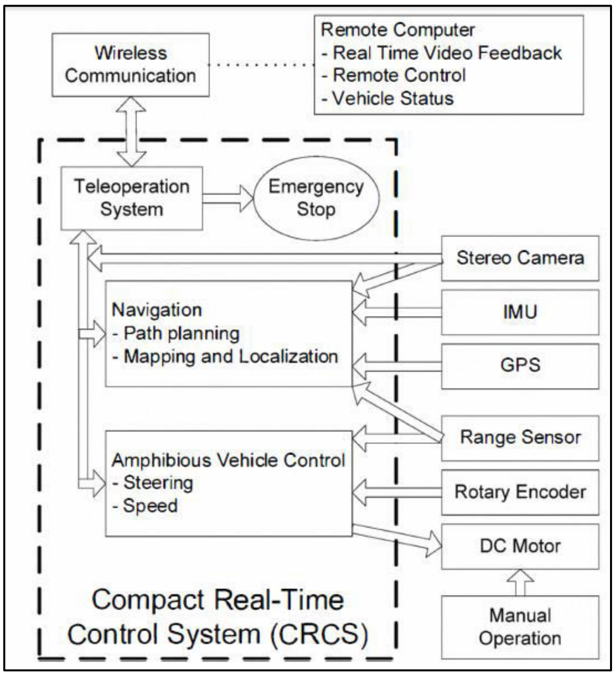

Figure-7. UTAR compact real-Time control system.

Teleoperation functional block gives ongoing input, position, speed and continuous real-time video all together for the administrator to know the status of the ALV in remote place. The communication mode among administrator and ALV can be manual, semi-self-governing or self-governing. The navigation functional block is a controller that incorporates routing, mapping and positioning together at once. ALV can see its environment with the stereo camera and this data will be utilized to navigate the ALV.

The vehicle control functional block drive and control the movement of a vehicle. It handles the data from sensors, such as range sensor, rotating encoders and after that creates control signals to DC engines

Other example of Autonomous applications implemented using FPGA includes works of Meng [21] and Mahyuddin *et al.* [22]. They had contributed for 3D reconstruction of an environment using camera with moderate power of consumption.

Yan Meng [21] conFig FPGA so that it is able to be reconFig on the fly and utilizes embedded processor in SoC environment for the mobile robot system. This method is believed to ease and shorten period of developing the system, and to efficiently integrate the FPGA hardware and microprocessor software. This brought together philosophy is to produce a control level framework of the system.

Self-reconfiguration is a special case of dynamic reconfiguration where the configuration control is hosted within the logic array containing the configuration control remains unmodified through out execution. This design brings advantages such as; the control logic is located as close to the logic array as possible, thus minimizing the delay associated with accessing the configuration port. It also provides a simple mechanism to implement the multi-agent communication protocol, thus fewer seperate discrete devices are required, reducing the overall system complexity. The proposed generic agent-based architecture using configurable SOC is applied to a real mobile robot system.

Work on autonomous vehicle by Mahyuddin *et al.* [22] is realized on FPGA platform, too. A robot with mobility is designed using neuro-fuzzy algorithm for avoidance of obstacle. This robot developed with FPGA development board. The program is coded with Altera Quartus® II design software, System-on-programmable chip (SOPC) Builder, Nios® II Integrated Design Environment (IDE) software, and FPGA development and education board (DE2).

This paper presents the designed obstacle avoidance program for mobile robot that incorporates a neuro-fuzzy algorithm using FPGA development board. The neuro-fuzzy-based-obstacle avoidance program is simulated and implemented on the hardware system using Simulation and weight training process are carried out with the aid of Nios® II IDE software. A mobile robot serves as the test platform of the program. An ultrasonic sensor and servo motors are used as the test platform's sensing element and actuator, respectively. With the aid of an established radio frequency (RF) communication between the mobile robot and FPGA board, the proposed algorithm is successfully implemented and verified.

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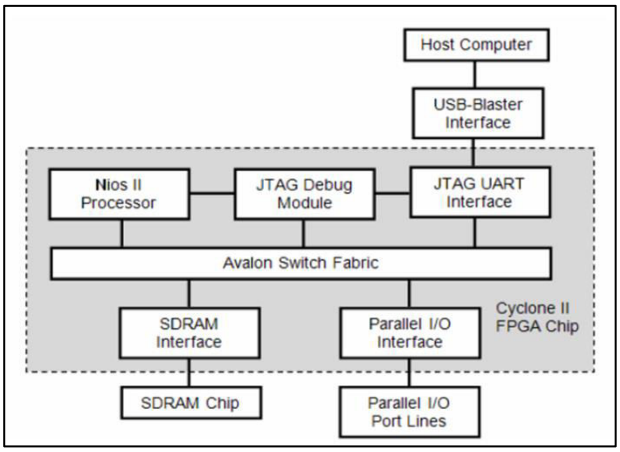

Figure-8. Designed hardware system [22].

System on Chip	Year Developed	Autonomous Application	Contributions
Helios (Xilinx Virtex-4 FPGA)	2006	Small autonomous robot	• 3D reconstruction of an environment using a single camera (static environment) • Moderate levels of power consumption
Agent-based Mobile Robot System (Xilinx Virtex-2 FPGA)	2006	Pioneer 3DX mobile robot	• Multi-agent based architecture framework • Transport-independent communication mechanism for multi-agent systems
Neuro-fuzzy based Obstacle Avoidance Program (Altera Cyclone II FPGA)	2009	Mobile robot	• Neuro-fuzzy based obstacle avoidance algorithm

Figure-9. Examples of SoC using FPGA as processing device.

Although the researches in [2,21,22] had utilized the FPGA platform, implementation of V2X system on autonomous vehicle is not yet accomplished. Our project may receive data other than deployed sensor within the vehicle.

Vehicular networking & autonomous vehicle challenges

Variety of applications, ranging from infotainment applications, such as media downloading, to traffic safety applications, such as driving assistance co-operative awareness, impose diverse requirements on the supporting vehicular networking technologies. These diverse requirements lead us to a number of research challenges. This section describes these research challenges.

These challenges includes:

a) Addressing and Geographical addressing,

b) Risk analysis and management,

c) Data-centric Trust and Verification,

d) Anonymity, privacy and liability,

e) Secure localization,

f) Forwarding algorithm,

g) Delay constraints,

h) Prioritization of data packets and congestion control, and

i) Reliability and cross-layering between transport and network layers

Addressing and geographical addressing

Some vehicular systems administration applications require that the addresses are connected to the physical position of a vehicle or to a geographic area. Mobility makes tracking and administrating of "geo-addresses" greatly difficult.

Risk analysis and management

Hazard investigation and administration is utilized to recognize and deal with the advantages, dangers and potential harm in vehicular correspondence. Arrangements on overseeing such assaults have been proposed, yet models of aggressor conduct are as yet absent.

Data-centric trust and verification

For some vehicular applications the reliability of the information is more valuable than the reliability of the hubs that are sending this information. Information driven trust and confirmation ensure the security of vehicular applications to guarantee that the sent data can be trusted and that the receiver can check the data, keeping in mind the end goal is to shield the V2X communication from the in-travel activity which brings security threats and assaults [23]. Open key cryptosystems can be utilized here.However the fundamental challenge is related with the overhead that is presented by the utilization of general public key cryptosystem, see e.g., [24].

Anonymity, privacy and liability

Vehicles accepting data from different vehicles or other system elements should some way or another trust the sender that produced this data. In the meantime, security of drivers is an essential basic right that will be ensured, in numerous nations, by laws. Protection can be given utilizing incognito vehicle characters. One of the principle challenges here is to improve of an answer that can balance the tradeoff between the validation, security

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and liability, when the system needs to (in part) reveal the communication data and its source to certain legislative specialists.

Interconnection resources on FPGAs

A basic issue in FPGAs is the complication of its interconnection resources. These resources directly affect the routability of the gadget. High routability is especially critical when some strict requirements are forced. Such requirements emerge when a FPGA is set on a printed circuit board, and a few changes in the circuit executed in the FPGA must be made. Since the circuit board associations are xed, the I/O assignment task on the FPGA needs to stay as before. Consequently, any adjustments in the FPGA setup must be made inside these restriction [25].

FPGA Tools challenges

Simplifying the hardware design process and adding more features and components to gain flexibility are making the CAD tools associated with these boards and the whole process software/hardware co-design process in general difficult and challenging especially for those in educational environment such as students and new designers.

Some of the issues include 1) Software compatibility issues, 2)builiding an SRAM model, and 3)Acessing SRAM [26].

METHODOLOGY

Autonomous vehicle construction by fpga

VHDL code will be written to program Field-programmable Gate Array to drive or halt the autonomous vehicle. The automated vehicle will utilize sensor data input, then to form an environment profile and processing the data from different sensors parallelly.

This parellelism is enhanced and crucial in design to avoid data delay. In order to achieve the required behavior, the VHDL formational and functional block should be guaranteed the readability and future maintenance of the code for updates on more sophisticated features, such as improving data security and to keep the user anonymous.

Using Altera Quartus Prime 15.1 Lite Edition, the developer may analyses and synthesis the HDL design with advance tools, such as Signal Tap II Logic Analyser, In System Memory Content Analyser, and In System Sources and Probes Editor. Resource utilization is maximize with the Altera software, which is the modest among similar software.

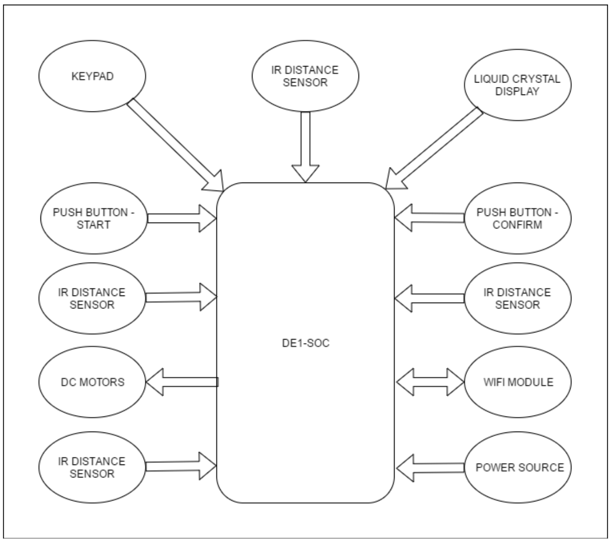

Figure-10. Autonomous vehicle and its connection.

Figures 10 and 11 shows the connection and module of our design of autonomous vehicle using FPGA. De1-SoC will be connected to 4 IR distance sensor, DC motor, 2 push buttons, keypad, external liquid crystal display, WiFi module and power source. A single clock will be used to ensure synchronization of data.

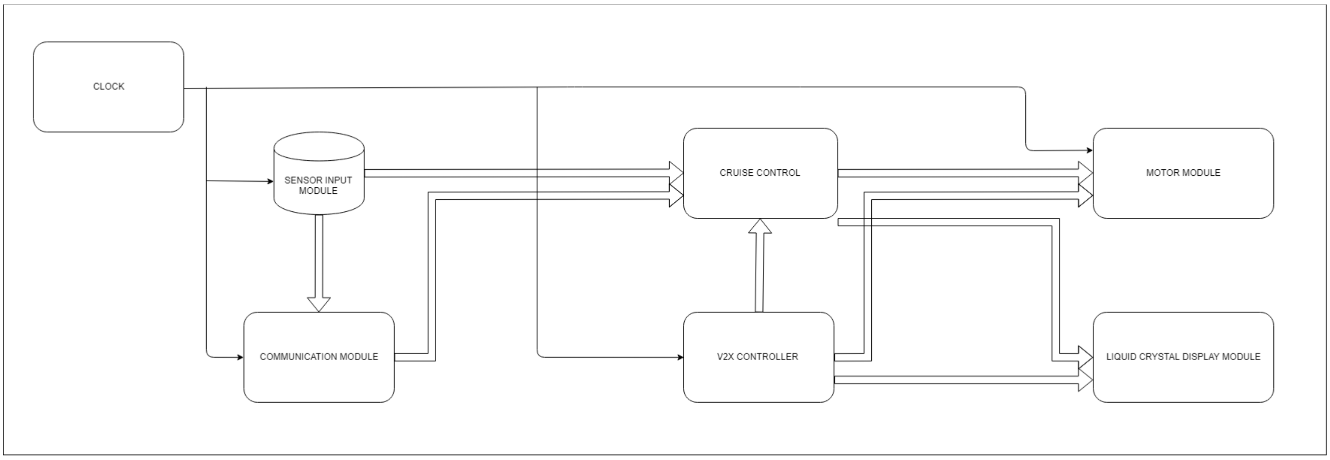

Figure-11. Top level view of FPGA module.

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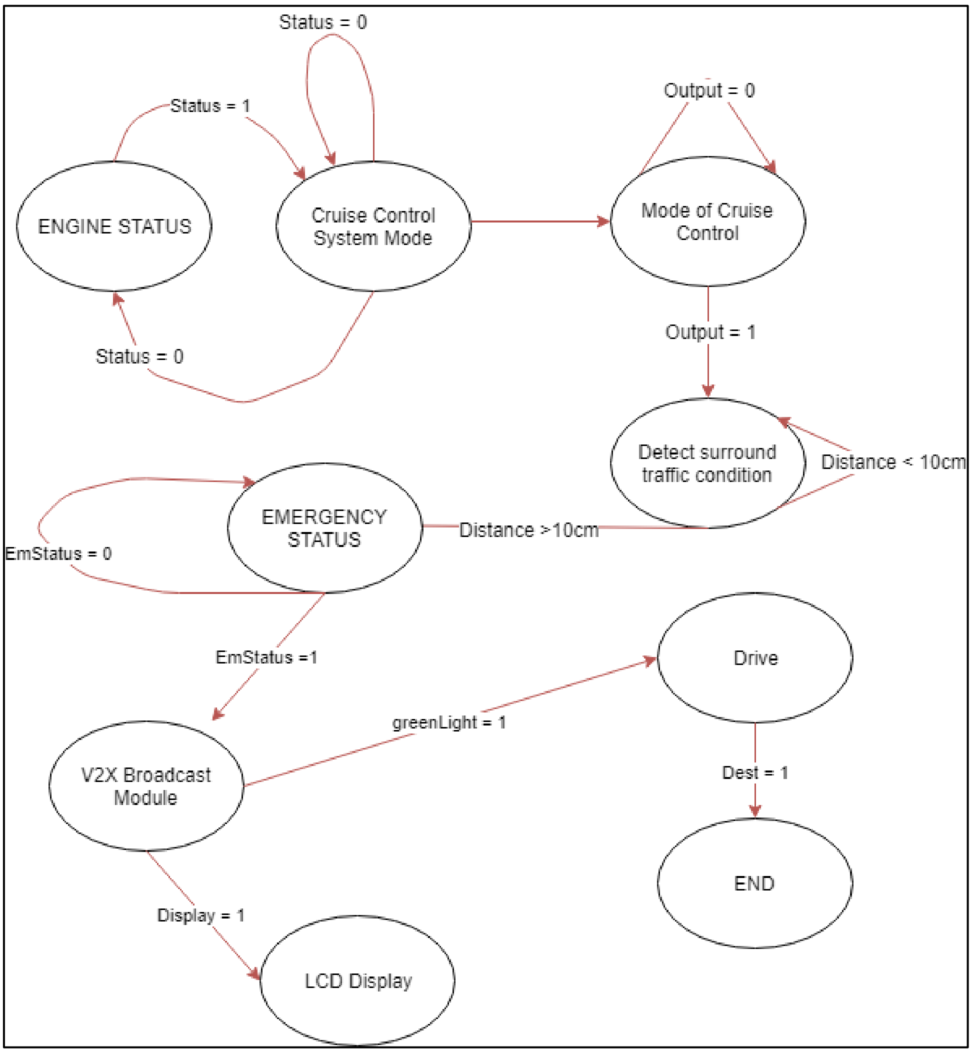

Figure-12. Finite state machine for autonomous vehicle.

From Figure-12, the vehicle is at rest at initial state. When start signal is initiated and sent to the vehicle, it will wait for signal to start driving or at rest. If it is detected to drive, it will first check for Green Traffic light signal. Next, if emergency status is detected, the autonomous vehicle will broadcast EM signal to the V2X network. Message receives from V2X network will always be displayed on the LCD. Lastly, when a green light signal is received, then it will drive itself.

SENSOR INPUT MODULE

This module is used to detect and process data input from sensor. These sensor include push button, switch and IR sensors. The processed data will then be sent to the cruise control module and V2X controller module.

CRUISE CONTROL MODULE

Used for acceleration, deceleration and movement of the autonomous vehicle, the Cruise Control module is the most vital module in the FPGA design. In the design, this module enhances parallelism to process important processes to decrease the processing time to the maximum. Where computational intensive processes is most suitable to be developed in the FPGA platform, Cruise Control module is developed such that output triggered by important messages is appropriates and uses least time.

Figure-13 shows the cruise control module that consist of input from binary data converted from sensor module, cruise control setting, analog to digital module, and output to control speed and rear of the vehicle.

LCD MODULE FOR PRESENTABLE DATA

This module is developed for the purpose of presenting relative data. DE1-SoC model Altera Cyclone V FPGA 5CSEMA5F31C6N will be programmed to show data obtained from V2X communication, as well as decision made by the autonomous vehicle.

Hence, from the LCD, the observer may get information. In this module, state machines and state generator is implemented to input every ASCII character in regular sequence serially to avoid improper timing.

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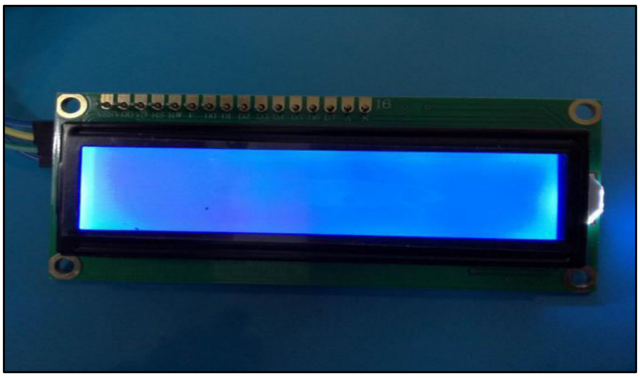

Figure-13. Liquid crystal display.

COMMUNICATION MODULE

The communication module helps the vehicle to serve as a node in the V2X communication. This module will set up a serial communication with external WiFi module and analyses the data.

The execution of processes is expected to take form in parallelism where information for different application can be underway in a manner that least latency can be achieved. The baud rate is115200, which the rate of data transmited per seconds.

Although the DE1-SoC itself may reach a higher baud rate, the throughput is limited by the low-cost WiFi module.

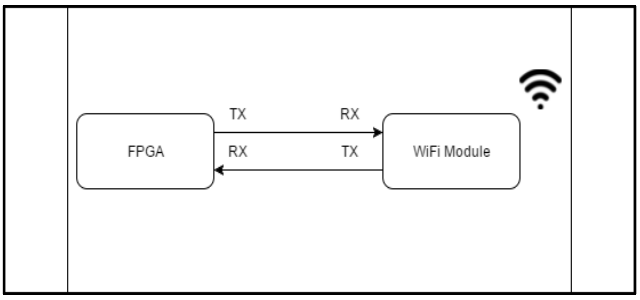

Figure-14. Bilateral connection between DE1-SoC and ESP8266.

From Figure-14, the connection between De1-Soc and ESP8266 is established using serial communication.

Android application development for vehicle to pedestrian

An application for pedestrian will be developed to connect the pedestrian to the V2X system. Figure-15 shows the user interface to be implemented in the mobile application.

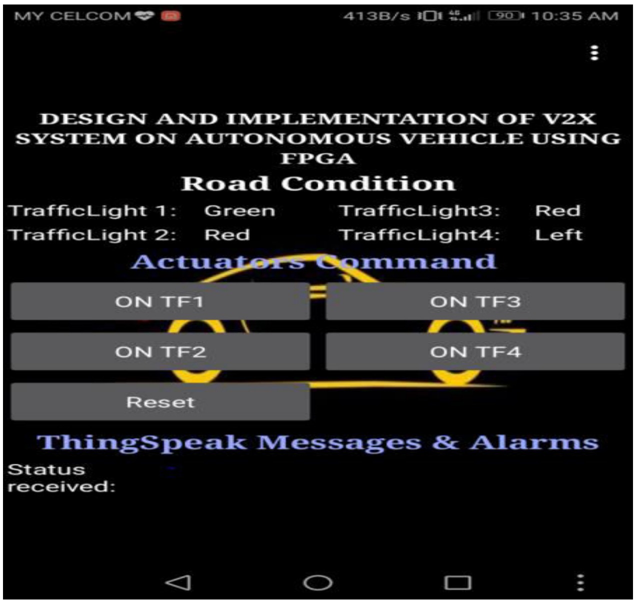

Figure-15. User interface of android application.

With the application, the pedestrian will be able to receive traffic condition at ease. Pressing the actuators command will request to on certain traffic light. After one of the command is pressed, the user need to press reset button.

FIRMWARE DEVELOPMENT

Firmware for other nodes of the V2X system will be developed next. The ESP8266 WiFi module, with its support of popular WiFi standards such as IEEE 802.11 b/g/n/e/i is a low cost module for fast implementation of V2X system with appropriate features.

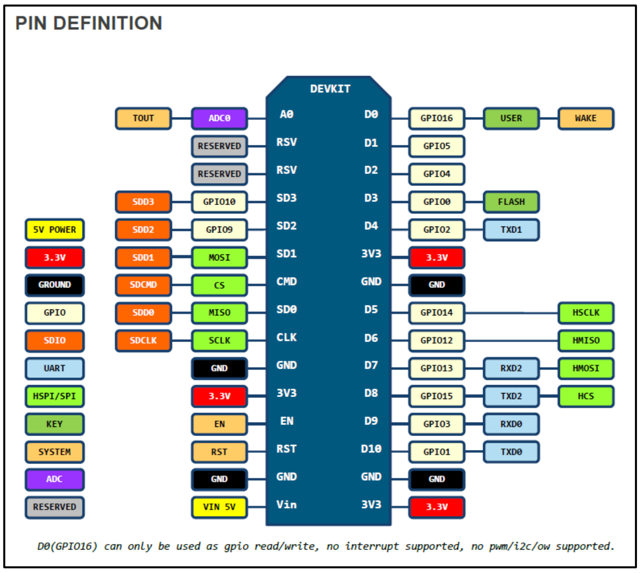

Figure-16. Pin mapping of ESP8266.

Figure-16 shows the pin mapping of ESP8266. It will be used for connectivity of vehicles, RSUs and traffic light. Several firmware will be developed for different

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node. 8 ESP8266 will be incorporated in the network and serve as a node to the V2X system.

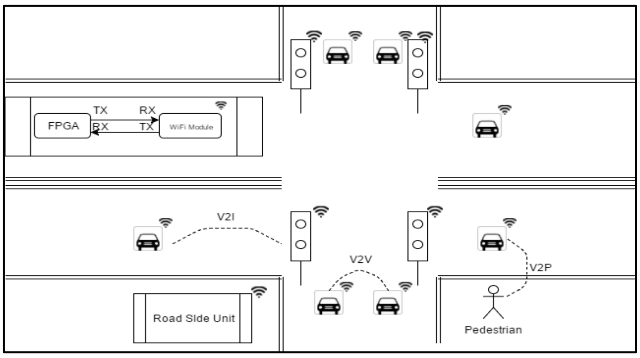

Figure-17. Scenario of V2X communication.

In Figure-17, the scenario of V2X communication and its implementation in this project is showed. Three types of communication, V2V, V2I and V2P will be established. The autonomous vehicle will be realized using FPGA and connected to the V2X network with WiFi module.

In this case, four firmware is needed to be developed. First, firmware for the autonomous vehicle needs to be able to establish connection to the V2X system and the cloud. The connectivity should be stable with low connection establish time for handshake. Serial communication needed to be enabled to transfer data to DE1 board to be processed by the autonomous vehicle.

Secondly, firmware for the RSU should be able to collect traffic information from traffic light, process, and issue instructions for SPAT purpose. Thirdly, firmware for traffic light should be able to collect relevant data and process data receive from Road Side Unit and act according to the SPAT policy.

Next, where the ESP8266 act solely as other vehicle on the network, their need to connect to the network to enable the RSU to calculate traffic flow condition and sent data to the autonomous vehicle for path planning to avoid road with congestion.

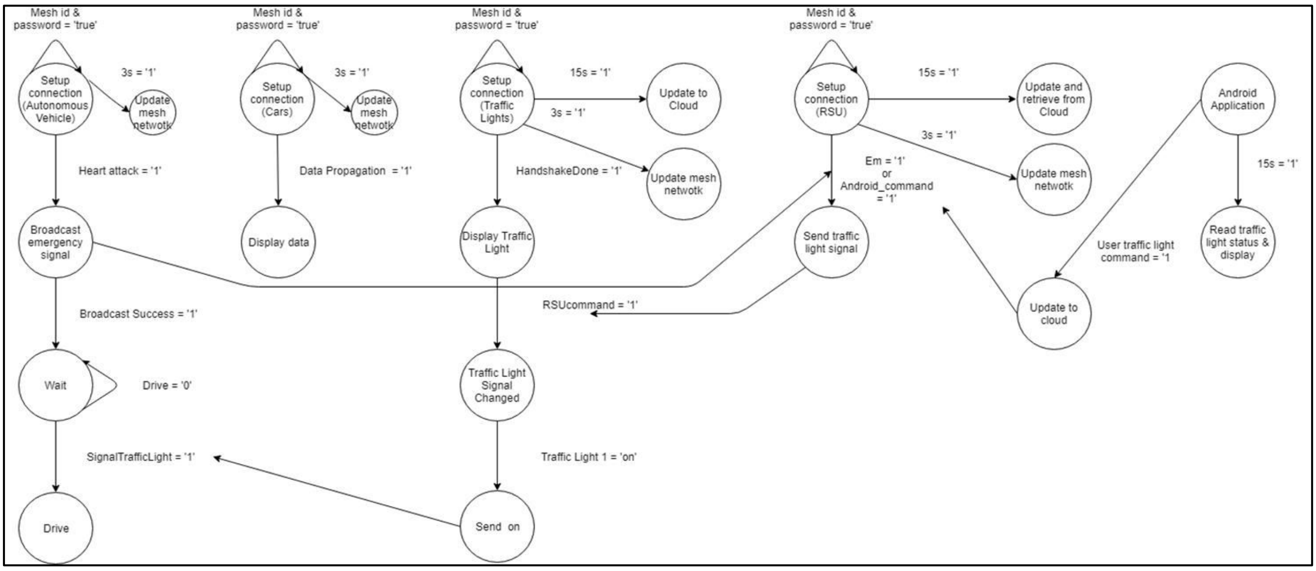

Figure-18. State diagram of V2X network.

RESULTS

To form a vehicle to everything network, we first form a mesh network with star topology. Next, autonomous vehicle will be connected to the mesh network. Formation of this mesh network allows transmit of message to any member of the network by specifying their respective MAC address. Hence, important messages such as EM (emergency signal) from autonomous vehicle will be able to transmit to other nodes, then, to notify hospital. This can be achieved even the autonomous vehicle does not has any internet connectivity. Next, utilizing Smart Phasing and Timing System, the traffic light will be able to initiates green light to let autonomous vehicle with EM condition to pass through first.

Forming mesh network

First, we integrated the mesh library into our design. This library is chosen due to its stability and features that best suite with our project. Hence, designer will need not to redesign how the network is structured or managed. Before integrating the library into our design, several test is carried out. The test focus on measuring signal strength & propagation delay of each nodes.

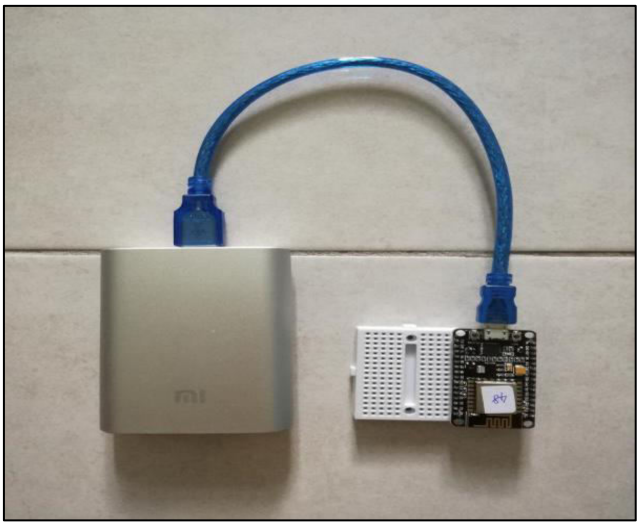

Figure-19. Wifi module with 5v of voltage support.

The voltage will then be converted to 3.3v. This WiFi module will be placed in distance with another module to test the propagation delay.

Figure-20. WiFi module connected to laptop. Delay calculated will be serially transmitted and displayed on the laptop.

The propagation delay is calculated using the following formula:

Delay = (t3-t0) - (t2-t1)

Where,

t0 = internal clock value when the packet was generated,

t1 = timestamp when request was received,

t2 = timestamp when response is generated,

t3 = timestamp when response is received.

The test is carried out in both indoor and outdoor.

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Table-2. Results obtained from calculating delay.

Distance	0	10cm	50cm	100cm	200cm	400cm
Result(us)	**5389**	**7185**	**3827**	**5013**	**3836**	**11506**
	5385	4028	3830	18073	16756	8579
	9405	28556	16662	6268	64569	13983
	9154	5312	14147	3368	5033	11944
	6852	4588	13303	4672	5467	24842
	6102	5037	5629	3785	16011	11282
	7275	5287	4145	16364	11480	9484
	11929	6760	5789	6749	32622	15806
	9379	5008	10178	7397	4574	8319
	10520	18921	9598	4036	3180	6302
	5684	5568	5820	4168	7845	4286
	11748	4272	13982	6455	12681	4004
	8961	14772	7119	21684	3872	7379
	12738	3945	9006	37246	3942	3879
	7815	7331	7475	8839	10636	4313
	9863	8186	8139	4419	4422	3368
	18358	4451	3612	10333	5170	4308
	18989	7694	5568	23458	8983	3342
	12096	4569	4241	6443	4411	4255
	11996	3365	5838	4087	4449	7882
	10696	6366	22452	4438	4724	6301
	11197	3392	10375	7954	4546	6231
	15731	4854	91807	13165	21380	4676
	3880	5676	20806	8871	13907	5373
	5315	10037	4902	10189	4111	12023
	6107	8482	4286	7826	4260	6282
	3372	4750	4581	14878	3475	3547
	5544	8140	44212	7925	6700	5574
	7609	7848	6339	11284	6925	6300
	15949	5360	5593	3959	10322	5075
	6594	7911	8278	4828	8592	3923
	5502	3716	5195	6389	3746	4841
	14700	4213	4229	5332	3742	5890
	7028	7442	4196	5527	3720	4885
	12899	3799	8792	10005	3425	3807
	11772	5187	8420	4697	3684	4647
	13370	6461	9736	12511	6993	33913
	7428	4055	17701	6838	4062	3723
	10560	7680	7823	3466	6303	7957
	7442	4002	4153	6405	19966	7830
	5492	10714	7862	8756	12906	46735
	12625	4995	4634	3640	4367	8543
	11808	5721	3883	8757	4519	3732
	17746	42460	3597	4196	5250	22451
	9888	17087	3961	5570	5738	81860
	13636	12560	4437	3736	3853	19592
	25277	10653	5399	3480	3648	4488
	5096	4547	3816	4684	4741	4918
	6812	4282	3818	3690	3287	5390
	11503	4658	7954	4431	4629	5751

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	0	10cm	50cm	100cm	200cm	400cm
Min.	3372	3365	3597	3368	3180	3342
1st Qu.	6648	4552	4252	4422	3972	4357
Median	9634	5464	5829	6397	4732	6060
Mean	10044	7838	10023	8206	8549	10306
3rd Qu.	12071	7895	9450	8863	8885	9258
Max.	25277	42460	91807	37246	64569	81860

Figure-21. Summary of the result.

50 test is carried out individually for respective distance. From Fig., the mean delay is within the range of 7895us to 10044us. This proves that in an indoor environment, for distance up to 400cm, the distance will not be a factor to propagation delay. During our application, the distance between each nodes will not exceed 400cm. Hence, this library is stable and suitable for use in our project.

Algorithm to implement smart phasing and timing system

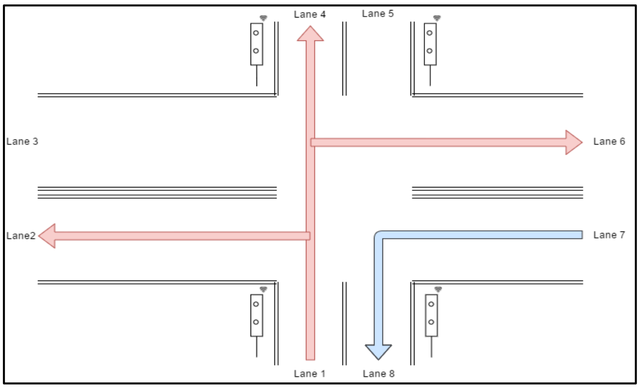

Figure-22. State 1. The red arrow and blue arrow indicates flow of traffic allowed to pass through.

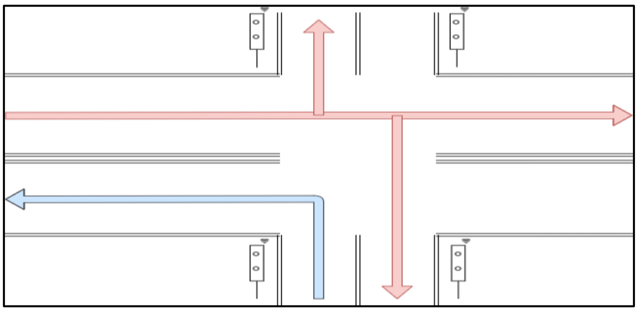

Figure-23. State 2.

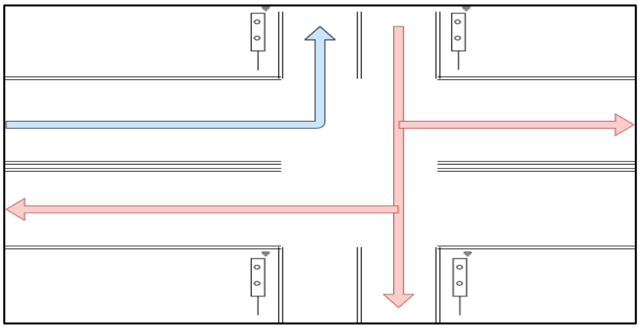

Figure-24. State 3.

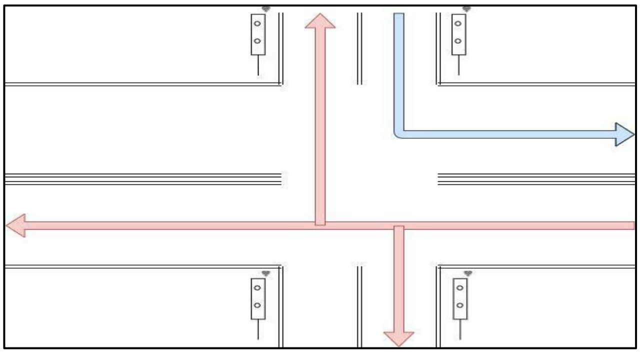

Figure-25. State 4.

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Table-3. Truth table of traffic lights.

STATE 0		TF1	TF2	TF3	TF4
	3s	green	red	red	left turn
	6s	yellow	red	red	yellow
	9s	red	red	red	red
STATE 1	3s	left turn	green	red	red
	6s	yellow	yellow	red	red
	9s	red	red	red	red
STATE 2	3s	red	left turn	green	red
	6s	red	yellow	yellow	red
	9s	red	red	red	red
STATE 3	3s	red	red	left turn	green
	6s	red	red	yellow	yellow
	9s	red	red	red	red

Figure-22, Figure-23, Figure-24 and Figure-25 is used to develop Table-3. Using this table, algorithm to implement SPAT on traffic light is developed.

```
Algorithm for TF_controller

1. Define I/O ports used by each traffic light
2. Declares variables start, state, color, state_chg, state_cb
3. Declares task
4. setup(){
        4.1. set baud rate
        4.2. set I/O modes
        4.3. initialize mesh network
        4.4. initialize scheduler
        4.5. add timer task for timing of lights to scheduler to call light() every 3s
   }
```

Figure-26. First part of algorithm.

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```
5. light(){

      5.1 if start is equal to 0
            then Serially sent "Start"
            Start = 1

      5.2 if state equal 0
            if color equal green
                  then changes the lights for all traffic light
            if color equal yellow
                  then changes the lights for all traffic light
            if color equal red
                  then changes the lights for all traffic light
                  if state_chg equal to 0
                        state = state + 1
                  else state = state_cb
      else if state equal 1
            if color equal green
                  then changes the lights for all traffic light
            if color equal yellow
                  then changes the lights for all traffic light
            if color equal red
                  then changes the lights for all traffic light
                  if state_chg equal to 0
                        state = state + 1
                  else state = state_cb
      else if state equal 2
            if color equal green
                  then changes the lights for all traffic light
            if color equal yellow
                  then changes the lights for all traffic light
            if color equal red
                  then changes the lights for all traffic light
                  if state_chg equal to 0
                        state = state + 1
                  else state = state_cb
      else if state equal 3
            if color equal green
                  then changes the lights for all traffic light
            if color equal yellow
                  then changes the lights for all traffic light
            if color equal red
                  then changes the lights for all traffic light
                  if state_chg equal to 0
                        reset state to 0
                  else state = state_cb
  }
```

Figure-27. 2nd part of algorithm.

```
6. recv_cb(){
        6.1 declares char[20] temp
        6.2 if RSU Data equal to state 0
                Serially send "change to state 0"
                state_cb = 0
                state_chg = 1
            else if RSU Data equal to state 1
                Serially send "change to state 1"
                state_cb = 1
                state_chg = 1
            else if RSU Data equal to state 2
                Serially send "change to state 2"
                state_cb = 2
                state_chg = 1
            else if RSU Data equal to state 3
                Serially send "change to state 3"
                state_cb = 3
                state_chg = 1
   }
```

Figure-28. 3rd part of algorithm..

By using algorithm above, SPAT has successfully been developed and implemented in this project.

An UART unit is adapted and incorporated into the autonomous vehicle. EM signal from autonomous vehicle is sent serially to the WiFi module, then broadcast to the network. Next, RSU will send out state change command to traffic light. Traffic lights successfully changed their state.

Next, autonomous vehicle will receive green light and on signal. Then, it will drives and pass through the traffic light.

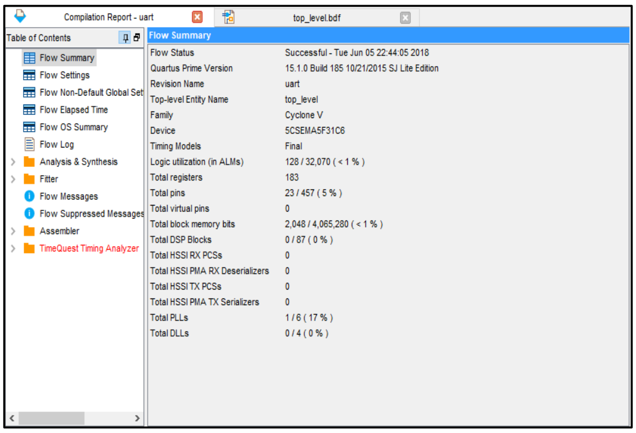

Figure-29. Synthesis report of FPGA usage.

Figure-29 showed the compilation report of DE1. From the report above, we can observed that PLL (Phase Lock Loop) is used at 17%. The total logic utilization (in ALMs) is less than 1%.

CONCLUSIONS

Autonomous vehicle implemented using FPGA is further enhanced with V2X connection. This report introduced several possible scenarios for future development of V2X system. During this project, not only a V2X network is form, it is a structured mesh network with star topology. Whenever one node possesses internet connectivity, the other nodes is able to connect to the internet with proper configuration. Next, the SPAT system will be able to change state according to command from RSU. The SPAT introduces flexibility to the current traffic system, which enable more robust arrangement of traffic flow and control. Last but not least, the ability of autonomous vehicle to communicate with other nodes on the road is the main purpose of this project. This goal has been achieved successfully.

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