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DESIGN AND IMPLEMENTATION OF EMBEDDED MULTI-SENSOR OUTDOOR ROBOT LOCALIZATION SYSTEM USING FPGA FOR ACCURATE NAVIGATION

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ABSTRACT

Recently, there has been a significant increase in the interest for robots. However, manually navigating a robot requires a skilled pilot who has highly constant concentration levels for sustained periods. Therefore, strong scientific interest has emerged in terms of developing solutions that allow a robot to navigate autonomously without needing constant human supervision. This is useful for a variety of potential applications ranging from surveillance and reconnaissance purposes, aerial filming, remote visual inspection of industrial sites, to military applications. First, a robot must be able to determine its location. Unlike humans, a robot does not have the sensing capacity and the ability to explore its environments and determine its location. Therefore, components like sensors need to be integrated on the robot. Examples of these sensors include GPS sensor, and accelerometer sensor. The robot then needs to be able to determine its destination and be able to create a route to get there. To do this, the robot must be able to generate paths to the destination and make a decision on which path to take. The FPGA DE0 Nano board offers a portable extensive computational platform that help to solve this current problem. It also has lower design complexity and the ability to be embedded to an outdoor robot localisation system. The path planning approach generates a route to the desired location. The GPS sensor was utilised to determine the positions for the current and desired locations. After information from the sensors was received, the DE0-Nano sent proper signals to the L293D to control robots motors. The DE0 Nano achieved a maximum operating frequency up to 1.3 GHz and total logic elements are 6,032. This means that the robot platform's frequency requirements were achieved to that level. Thus, high performance was achieved by using FPGA with multi sensors.

Keywords: embedded system, FPGA, robotics, localization system, multi sensor.

INTRODUCTION

Nowadays, there is rapid growth in the widespread utilisation of auto-navigation. Autonomous robots refer to robots that perform tasks on their own in an unstructured environment. There has also been a rapid increase in the navigational aids that allow an autonomous robot to navigate to its destination without requiring human intervention. Autonomous also means that the robot is capable of self-piloting in order to perform different tasks under unstructured or structured environments. In the absence of human-guidance, the robot must still be able to make decisions based on on-board data processing.

The embedded systems are considered as a type of reactive system, which means that these systems continuously react to the environment and that most of them have the real-time response characteristics. The current trend in the development of embedded systems is veering away from being restricted to one particular function and is instead focused allowing flexibility to modify, add, and even delete some of the embedded system's sub-functionality units. As a matter of fact, these changes could even be taking place while this research is being written. Thus, the goal is to make embedded systems that are as fast and small as possible. One of the several application areas that are covered by embedded systems is the mission critical area, which includes robot localisation [1].

Outdoor localization of mobile robots is a difficult task for many reasons. Some range sensors like laser range finders, which play an important role in indoor localization, are not suitable for outdoor localization because of the cluttered environment. GPS can give valuable position information [2].

Furthermore, global positioning system (GPS) is another component that is needed on autonomous robots. The GPS is responsible for finding the robot's default direction. It does this by utilising GPS navigation to generate the shortest path for the robot to be able to reach its goal based on its current position. GPS and detection sensors work independently from each other. However, GPS is also limited because it does not work indoor or in areas that are obstructed. Nonetheless, object detection, path planning, and obstacle avoidance during accurate navigation are important concerns for mobile robot localisation systems. The current platform faces many issues, which include the problem with accuracy as the robot tries to reach the destination.

It is vital for autonomous robots to know their location and be capable of navigating to other locations. Localisation refers to the process of finding one's location on a map. However, how can a robot be able to localise on its own? The most popular type of navigation and localisation is to utilise a map and to combine this information with sensor readings and some type of closed-loop motion feedback. Nonetheless, a robot must be able to do more than just localising on its own. Often, the robot must also have the ability to avoid obstacles, go back to the main path, and accurately reach its destination by using multi sensors.

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DE0 Nano solves the problems of constrained I/O and resources and low processing speed. DE0 Nano is becoming the leading processing unit for this system of localisation. In order for the robot to master those sensors, one has to test the characteristic of the sensors and how they impacting the robot's stability. Afterwards, the DE0 Nano interface was integrated with the sensors and the robot. Then, to overcome design challenges, HDL and other mega-function modules were used.

The code was divided into individual parts and every part was considered an independent process concurrently executed. In this project, GPS was utilised to calculate the current and desired location. Then data is saved and a map with the shortest path to the destination was drawn. The GPS then forwards the data to the PWM, which controls the robot's movements.

RELATED WORK

Robot localisation by using agricultural wireless sensors as artificial landmarks for estimating distance, the Received Signal Strength Indication (RSSI) employing Bluetooth (BT)-based sensors/technology was characterised. This helped in mapping a procedure based on the Histogram Mapping concept for evaluation. Based on the results, it was confirmed that employing agricultural wireless sensors helped in robot localisation procedures, especially in critical moments, as well as assisted in creating redundant localisation information [3].

A multi-robot distributed cooperative localisation method that employed dead reckoning and fusion of sound. First, the position and orientation by dead reckoning are computed by each robot. Periodic fusion of the results of dead-reckoning with the sound-based relative localisation though the Extended Kalman Filter (EKF) algorithm was done to correct the accumulative error of dead reckoning. To carry out indoor experiments, two self-made small mobile robots were adopted, where the known robot was integrated with a sound receiving device and the unknown robot was integrated with cheap sound-transmitting device. A comparison was carried out for the EKF fusion results, the dead-reckoning results and the motion capture localisation to determine the proposed sound based on EKF algorithm. This could be the new solution to solve the multi-robot localisation problem [4].

The localisation approach for autonomous mobile robots Laser Radar (LADAR) and the Inertial Measurement Unit (IMU) were used to accomplish the all-terrain localisation function. First of all, a fuzzy filter is built to determine the mobile robot's position for the multiple-input nonlinear localisation system. Then, an efficient evaluation index is developed to confirm the similarity of landmarks extracted though adjacent data frame, which assisted the mobile robot in realising self-correction functions [5].

A 2D simultaneous localisation and mapping approach that could be applied to multiple mobile robots, Data of 2D LIDAR sensors were used to present strategy for construing a dynamic representation according to Signed Distance Functions (SDF). Registration and data integration were performed simultaneously by multi-threaded software architecture that allowed drift-reduced pose estimation of multiple robots. The provided experiments demonstrated application with a single and multiple robot mapping that employed simulated and public accessible recorded data as well as two actual robots that operated in a large area [6].

A Wi-Fi-based solution for the mapping and localisation problem faced by a team of heterogeneous robots that operated in unknown environments. Wireless signal strengths that were broadcast from access points were exploiting to allow the robot possessing a large sensor payload to build a Wi-Fi signal map that could be shared and used for localisation by robots lacking sensors. In this approach, as a classification problem, the Wi-Fi localisation is cast. Incoming Wi-Fi signals were processed through online clustering algorithms, which were incorporated into an online random forest. A Monte Carlo Localisation algorithm was employed to increase the robustness and the results of the online random forest classification were exploited through the sensor model. The proposed algorithm was run in real-time to facilitate operation of robots in completely unknown environments, in cases where priori information such as the access points' location or a blue-print was not available. This approach is not only compared with other algorithms in a comprehensive set of experiments, but has also helped in validating the results across different scenarios that include both outdoor and indoor environments [7].

The positioning schemes in sensor networks for use in a sensor node positioning, a framework is established to monitor the signal strength relative to the transmission protocol AODV as well as ZigBee's placement. Accordingly, two positioning schemes were presented to treat outdoor and indoor environments. Compared to indoor scheme, the outdoor scheme employs the estimated distance to predict the sensed node's most likely position. Based on the studies, it was confirmed that these methods did not require any location database or location fingerprinting in advance. The accuracies of different node placements were studied based on multi-floor and one-floor environment cases for indoor positioning. For outdoor cases, two positioning algorithms were employed for investigation, where the performance was analysed through field tests [8].

A continuous online mapping of mobile robot to determine the properties of road that allowed the robot to move from a certain start position to pre-determined goal, while detecting and discovering the roundabout. The sensors fusion integrated camera, laser range finder and Odometry in a new platform, which were employed to determine the robot's path and localisation within its environments. Camera and laser range finder were employed to develop local maps in a bid to recognise the border parameters such as road width, roundabout and curbs. Based on the results, the robot's capability with the help of the proposed algorithms showed effective identification of the road environments as well as helped in building a local map for the road's roundabout and following [9].

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ALTERA DE0-NANO BOARD

The DE0-Nano board was able to present a compact-sized FPGA development platform that is appropriate for use in a broad range of portable design projects like mobile projects and robots. The DE0-Nano is suitable for utilisation in embedded soft processors. It possesses a powerful Altera Cyclone IV FPGA (with 22, 320 logic elements), 2 Kb EEPROM, 32 MB of SDRAM, and a memory device that has a 16 Mb serial configuration. In order to connect to real world sensors, the DE0-Nano uses an included National Semiconductor 8-channel 12-bit A/D converter.

Furthermore, it has a 13-bit analogue device and a 3-axis accelerometer device. For FPGA programming, the DE0-Nano board makes use of its built-in USB blaster. The board powered either by an external power source or this USB port. The board also has expansion headers that utilised to help attach to different Terasic daughter cards or other devices like actuators and motors. Inputs and outputs include 8 user LEDs, 2 pushbuttons, and a set of 4 dip-switches [10].

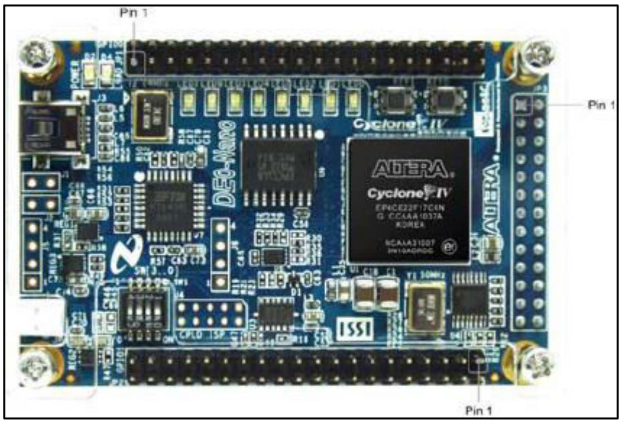

Figure-1. DE0-Nano board [10].

The accelerometer sensor has been utilized with the DE0-Nano when got the output data from the control panel which provided by Terasic.

LOCALIZATION ROBOT DESIGN

The localisation robot's position was generated by the GPS (VK2828U7G5LF) and was consistently updated. Thus, GPS was utilised to determine the localisation robot's current position and its arrival on the final destination.

RS232

Since the transmitter did not convey a clock, data bits were received using predetermined signals. An oversampling of 16 times was used, which means that the baud rate is 16 times and that sampling of the serial data bit is done 16 times. A baud rate generator is included in the UART receiver module to generate a sampling signal that has 16 times the frequency of the designed baud rate of the UART. It was implemented using a counter, which produces ticks as sampling signals. In this paper we chose 19200 as the GPS sensor's baud rate. On the other hand, the sampling rate used was 307200 ticks per second (1).

$$19200 \times 16 = 307200 \quad (1)$$

$$50000000 \,/\, 307200 = 162.76 \quad (2)$$

Based on Eq. (2), the system clock rate is50 MHz. Furthermore, the calculations revealed that mod-163 counters were needed to create the baud generator. This technique was used to lessen the error during the process of receiving GPS data.

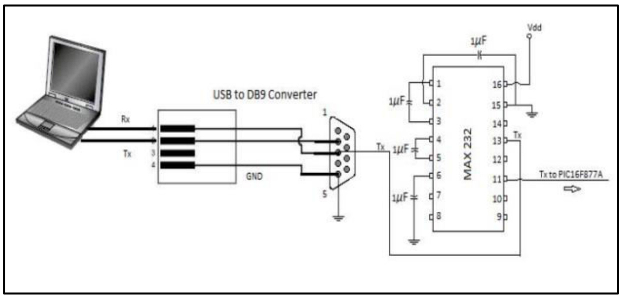

Figure-2. MAX232 Circuit with USB Serial Communication [11].

MAX232 is considered a serial RS232 to TTL/CMOS level converter. This means that it converts the +/-10 V serial RS232 signal to one that is a TTL/CMOS level 0 to 5V. This is an important connection since it allows the laptop and PIC microcontroller to communicate. Because most laptops these days do not possess a serial communication port, this design needs a USB to DB9 converter [11].

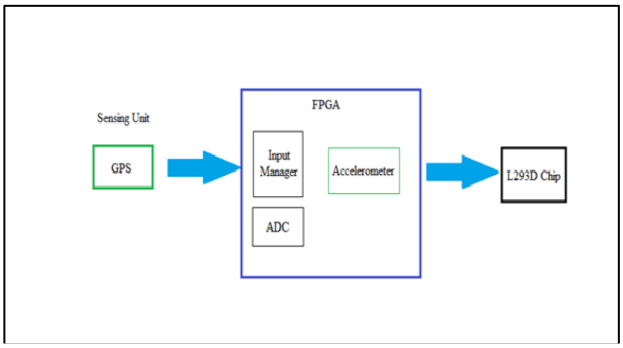

Figure-3. The top view design of the robot.

A: GPS

GPS receiver VK2828U7G5LF with TTL output was selected from the RS232 and used to acquire the attitude of the current position and the desired location. It was operated with the NMEA0183 protocols.

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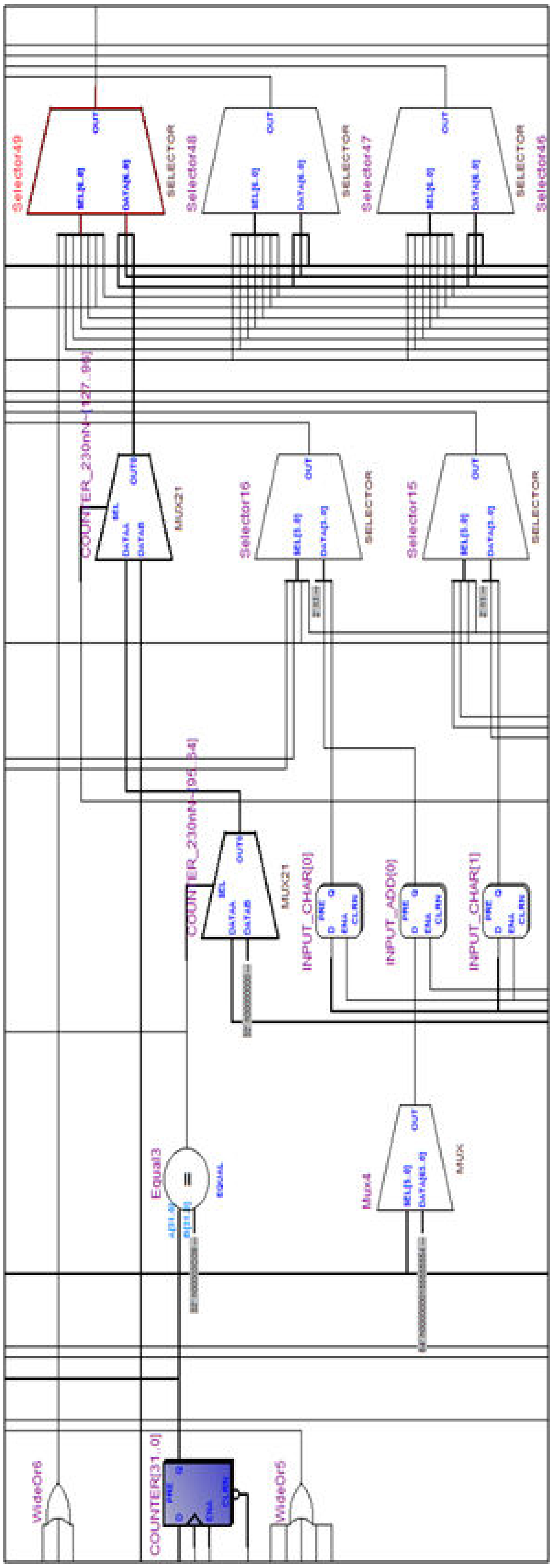

Figure-4. GPS RTL.

B: ADC

The analogue input signal produced by the sensors was transformed by the ADC and turned into the digital signal that DE0 board is capable of processing. This built-in ADC on DE0 Nano board is of the model NS ADC128S022. A 12-bit A/D input is available and used to read analogue inputs with voltages between 0 to 3.3V, a characteristic which restricts DE0 Nano board. Due to hardware safety issues, the DE0 Nano was only made to process 3.3V.

C: Input manager

The input manager is a module that controls the formatting data which get it from different sensors and make it ready to deal with the processing unit.

D: Accelerometer

An accelerometer sensor ADXL345 with the DE0-Nano it is tested by using the Control Panel which given from Terasic. At the same time, the DE0-Nano board is bending toward four directions.

E: L293D chip

To control the motor's direction, a VHDL code was used. The variations in the output of the L293D chip allowed the robot to perform different movements such as moving forward, turning right, and so on. The L293D has two built-in H-bridge driver circuits. This means that there are two DC motors that are simultaneously driven. Among the 16 pins of the L293D chip, pin pairs 2 and 7, 10 and 15 controlled the motor operations. An input at 00 or 11 stops the corresponding motor while an input of 01 and 10 allows the motor to rotate in a clockwise and anticlockwise direction, respectively. To activate and start the motor, pins 1 and 9 have to be enabled.

PATH PLANNING ALGORITHM

Dijkstra's algorithm solves an all-shortest-path problem in a weighted graph. Each vertex represents a location on a map and is connected to one or more other vertices via weighted edges, the weight representing a distance or cost incurred by following this edge. After defining a destination or reference vertex, the algorithm iteratively calculates a distance potential in every vertex which represents the distance to the destination node.

$$N = Width * Y + X \qquad (3)[12]$$

The shortest path from any starting vertex is found by subsequently following the edge to the neighbouring vertex with the lowest potential. A possible representation of a map generated by a mobile robot's sensors is a simple two dimensional binary map, where a logical zero represents free space and a logical one represents obstacles. This map is converted to a graph by placing a vertex in every pixel of the map and connecting it with eight edges to its eight neighbours. The weights result from the simple Euclidian distance of 1 to orthogonal neighbours and $\sqrt{2}$ to diagonal neighbours.

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Obstacle vertices get an infinite weight or are not connected at all [12].

Table-1. Generates Movement Operation.

Pin L293D chip	Motor 1	Motor 2	Enable
1			_
9			_
2	Forward		
7	Backward		
10		Forward	
15		Backward	

PWM

In PWM, the wave's time period remains constant and the time when the signal stays high is modulated or varied. Furthermore, the average DC value and duty cycle of the signal are varied as well. PWM offers a powerful way to control analogue circuits with the assistance of a digital system's output [13].

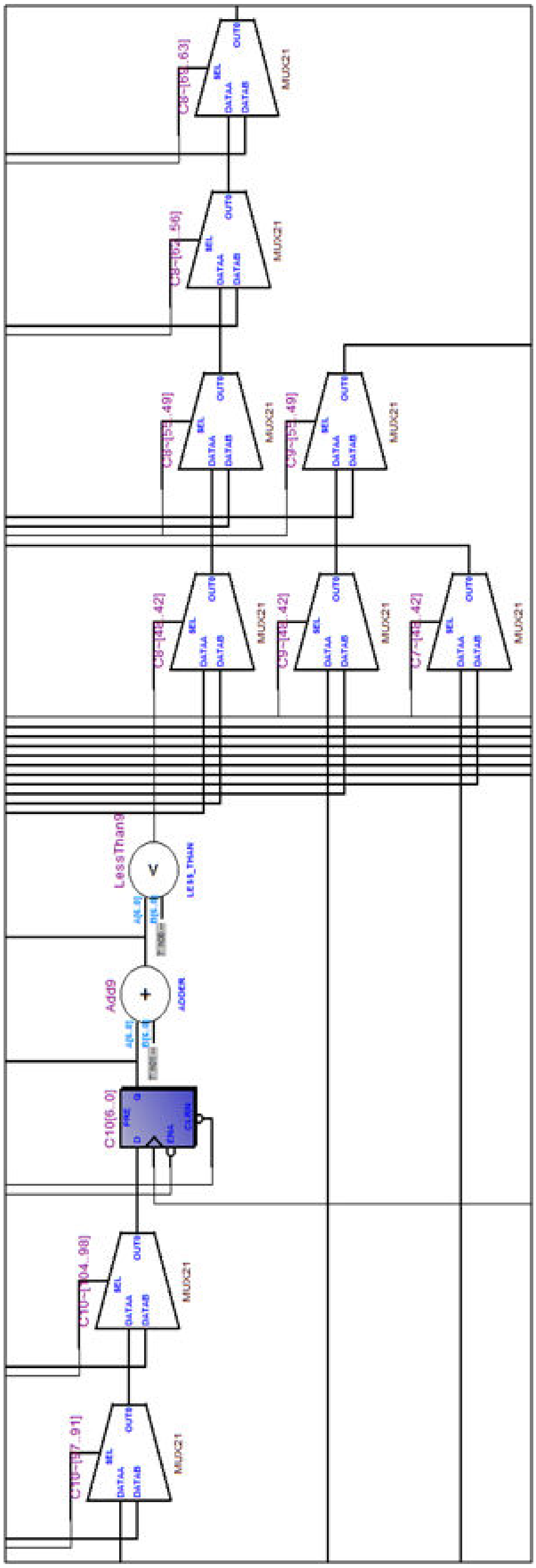

Figure-5. PWM RTL.

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From Figure-5 it show the RTL of PWM which control the motion of motors.

RESULTS

The auto-navigation system is designed using Quartus II 13.0 SP1 and FPGA design. The using of GPS receiver module is to get the data of location and information of the time in a predefined message frame through RS232 asynchronous serial communication. The GPS receiver module utilized with the FPGA and decade transmit message like GPS longitude and latitude with proper baud rate. So that, the mainly used of the paper is to design FPGA based GPS data acquisition and processing system. In addition, the main role of RS232 which is 9-pin package is used as interfacing unit. Each data to serial transmission, each serial data was constituted by the parity bits, data bits, and star bit.

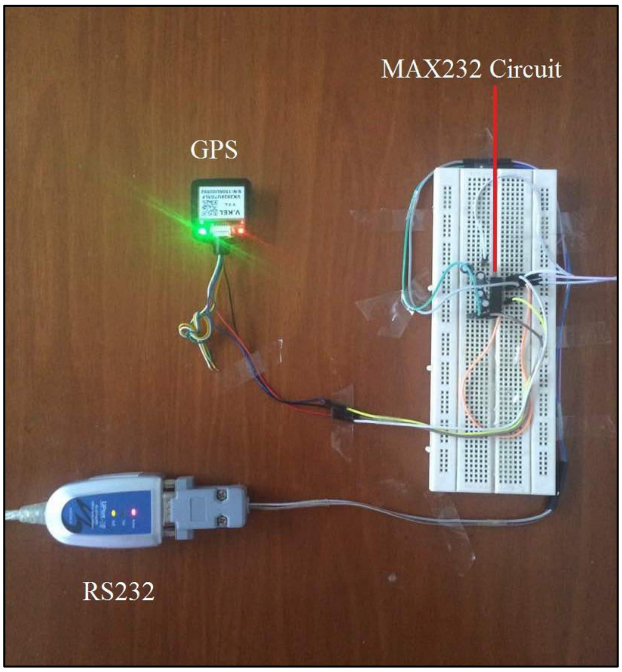

Figure-6. Connections of GPS with RS232.

After connected with UART the GPS data information has been viewed by using PComm Terminal Emulator. The six data frames of data is available collected by GPS like $GPVTG, $GPGGA, $GPGSA, $GPGSV, $GPGLL and $GPRMC. But only one has been used from all frames of data which collected by GPS. Therefore, $GPGGA was selected and the other frames has been filtered by using commend. GPGGA are data information stand for date, time, longitude, dimension and speed. The GPS sensor with NMEA0183 protocol provides different types of the output like: GSA, GGA, VTG, GSV, RMC and GLL. Figure-6 indicates the testing results for the GPS connected to the laptop using RS232 and read in PCOMM.

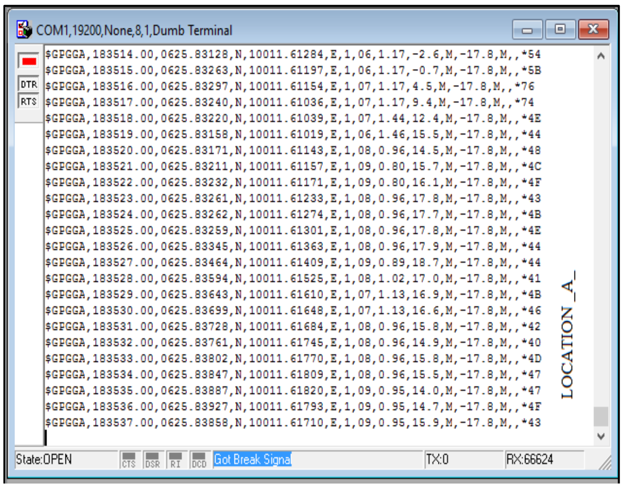

Figure-7. Output data of the GPS sensor when read in the PCOMM.

From Figure-7 above it shown the result of GPS sensor which got it by connected the GPS to the computer using RS232 and read the result of localization in PCOMM in first location.

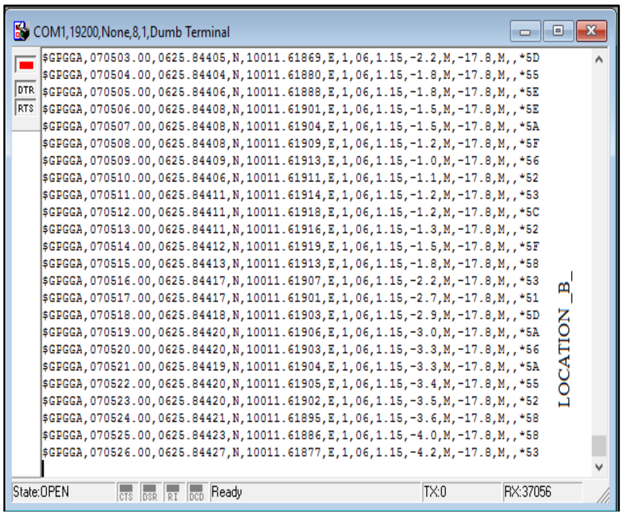

Figure-8. The result of the GPS sensor when read in the PCOMM.

From Figure-8 it shown the result of GPS sensor which got it by connected the GPS to the computer using RS232 and read the result of localization in PCOMM in another location.

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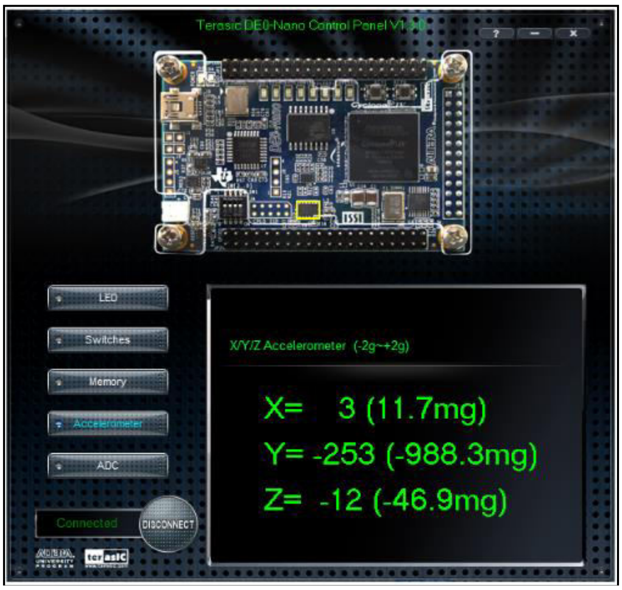

Figure-9. Accelerometer output data from the Control Panel.

From Figure-9 above it shown the result of the accelerometer sensor which has been tested with the DE0-Nano when got the output data from the control panel which provided by Terasic.

Table-2. Output reading when changes the direction of the DE0-Nano.

Direction	The Reading of Accelerometer		
	X	Y	Z
Forward	± 0	Increase toward positive number	Decrease from 255
Backward	± 0	Decrease toward negative number	Decrease from 255
Bend Left	Decrease toward negative number	± 0	Decrease from 255
Bend Right	Increase toward positive number	± 0	Decrease from 255

The localization robot controlled by DE0-Nano show in Figure-10 below.

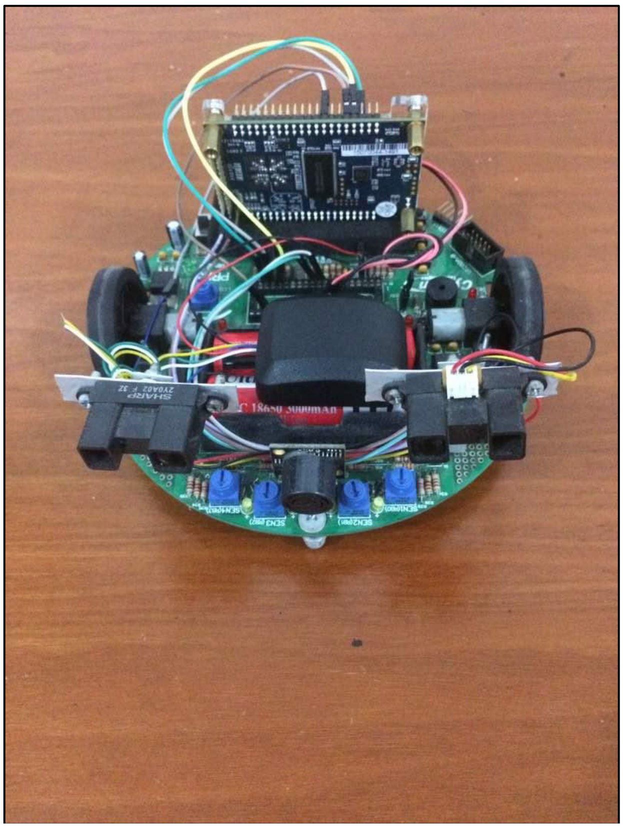

Figure-10. Robot controlled by using FPGA DE0-Nano.

PIC was removed and the motor's motion was completely controlled by FPGA DE0-Nano instead. Figure-10 shows the robot that is now being controlled by the utilisation of FPGA DE0-Nano.

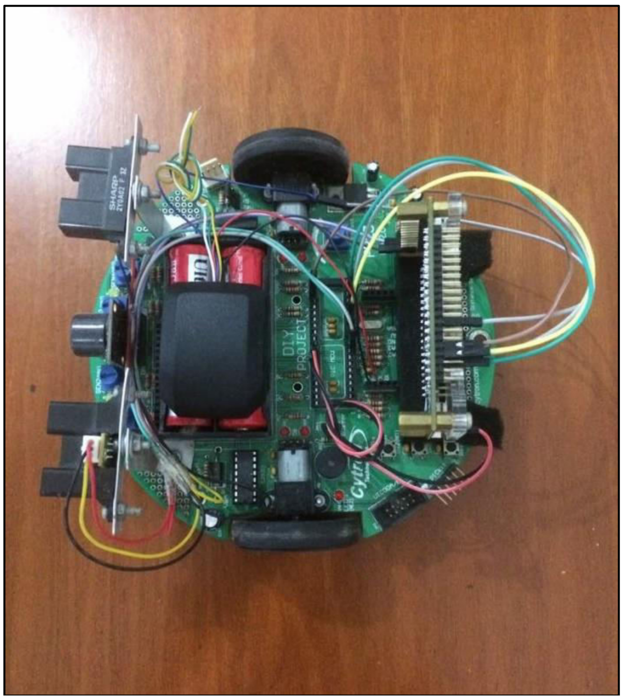

Figure-11. Robot controlled by using FPGA DE0-Nano.

From Figure-11 above it show the robot localization after controlled the motor's motion by FPGA DE0-Nano.

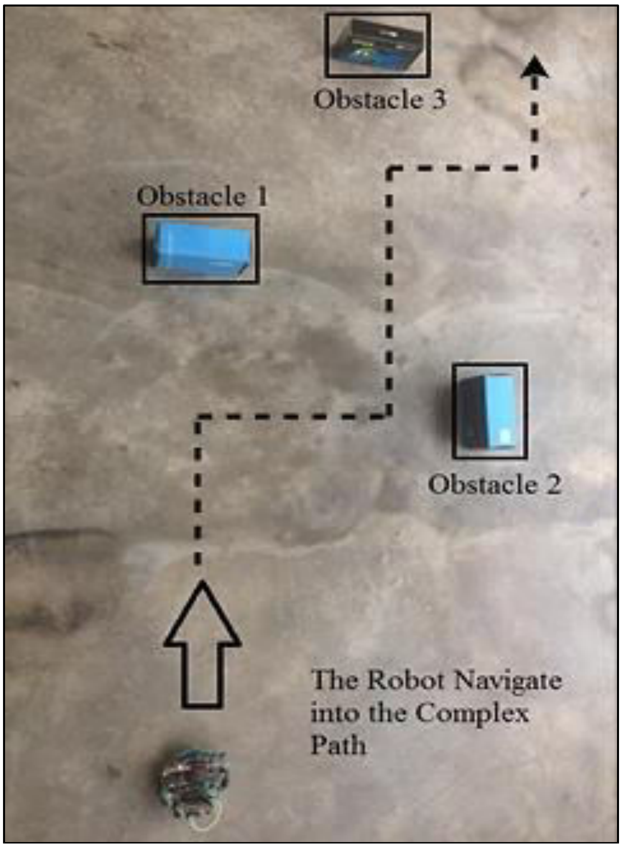

Figure-12. The Robot During Navigate to the Destination Third Path.

From Figure-12 it show the robot completely working during the accurate navigation in the path in order to reach the destination autonomously with FPGA by using DE0-Nano.

Table-3. Total Tapped Resources for the Project.

FPGA Recourses	Used by System	Percentage
Timing Models	Final	_
Total logic elements	6,032/ 22,320	27%
Total combinational functions	6,017 / 22,320	27 %
Dedicated logic registers	890 / 22,320	4 %
Total registers	890	_
Total pins	63 / 154	41 %
Total memory bits	35,843 / 608,256	6 %

CONCLUSIONS

The paper objectives have been achieved successfully. Among the duration to completing the paper, a lot of knowledge was gained and learning from trier and error on how to design the autonomous navigation system for embedded robot outdoor localization system. There are many aspect need to be considered during designing process and gained a lot of experience from this paper. This paper is portrays the design and implement active embedded multi-sensor outdoor robot localization system utilized FPGA to achieve the high performance. The main point is to design and implement of embedded multi sensor outdoor robot localization system using FPGA DE0-Nano board. The high performance here is emphasizing about the complexity of localization system implement on the platform, flexibility and the frequency of processing unit. The result that was highlighted in this paper has been achieved.

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