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Design and Implementation of Artificial Neural Networks for Mobile Robot based on FPGA

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Abstract—The world has seen great interest in intelligent systems and its control methods because they are provided distinctive service to humanity in civil and military purposes. In this paper presented the design and implementation of the intelligent controller system by Artificial Neural Network (ANN) for a laser mobile robot system to avoid obstacles in unknown environment. Back-Propagation (BP) method used to train the ANN. The system design was implemented and downloaded in FPGA board type Xilinx Spartan-3 XC3S700A. Four DC motor were used to move the mobile robot. The MATLAB program used to train the ANN. The mobile used IR sensors to detect the obstacles. The MSE get from the training the ANN is $3 * 10^{-7}$ which is considered suitable accuracy in robotic system.

Index Terms—ANN, BP, Controller, FPGA, Laser, Robot, Training.

1 INTRODUCTION

The definition of Robot is a machine that can be programmed and capable of manipulating solid objects, it includes a computer or microprocessor. Originally robots were intended to replace human workers in automotive industry which was suffering from industrial relations problems at the time. It was thought that robots would be universal machine, capable of rapid reprogramming for a wide variety of tasks. The robotic system have large field, and have some of features such as the safety, accuracy and reliability in other to the ability of moving in different environment. This paper dealt with a four wheel DC motor mobile robot [1].

Artificial Neural Network (ANN) is computational networks designed to simulate the network of the biological human central nervous system in basic behavior and components. The importance's features of the ANN are the ability of learn from the environment; improve its performance through learning and the possibility of the implementation of the tasks in a wide range of applications [2]. The Back-Propagation (BP) method is commonly used in learning algorithm for feed forward neural network. It's considered supervised algorithm required target in the operation of training to perform the desired function. BP improved by sub-algorithm to optimize its performance [3].

The term "laser" originated as an acronym for "Light Amplification by Stimulated Emission of Radiation". A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. A laser differs from other sources of light because it emits light coherently. Lasers can also have high temporal coherence which allows them to have a very narrow spectrum, i.e., they only emit a single color of light. Spatial coherence allows a laser to be focused to a tight spot, enabling applications like laser cutting and lithography. Temporal coherence can be used to produce pulses of light as short as a femtosecond. Spatial coherence also allows a laser beam to stay narrow over long distances (collimation), enabling applications such as laser pointers.

The rapid advanced in the digital technologies gives to the designers the option of choice verity type of controller such as: Programmable Logic Device (PLD), Field Programmable Gate Array (FPGA), etc. FPGA is an Integrated Circuit (IC) which contains a large number of logical components used to implement logical circuits just like hardware. It can be reprogrammed to execute a wide range of functions just like computer hardware. FPGA contains configurable (programmable) blocks of logic along with configurable interconnections between these blocks and has programmable I/O. Depending on the way in which FPGAs are implemented, they can be programmed a single time or be reprogrammed a number of times [4].

This paper aims to present the design and implementation of intelligent laser controller using artificial neural networks on FPGA platform based on drive wheel mobile robot. The building of the ANN was well suitable to realize the experiments for robotic system. The hardware implementation of proposed system by ANN and FPGA gives massive parallelism with high speed of implementation and low cost modifications. The laser used as switch as on/off to the movement of the mobile robot.

2 THEORETICAL BACKGROUND

These sections explain the theory used in research paper:-

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2.1 Artificial Neural Networks (ANN)

An artificial neural network is characterized by first a basic topology that defines how the neurons are interconnected and how they transmit information from one to another and second a learning rule that defines how the strength of the inter-neuron connections (called "synapses") change with time as different external stimuli are provided. Recent advances in neural sciences and microelectronic technologies have provided an excellent meaning to boost the computational capability and efficiency of complicated engineering tasks by several orders of magnitude [5].

The Levenberg-Marquardt Back-Propagation (trainlm) is used to train the intelligent controller and updates weight and bias values according to Levenberg-Marquardt optimization to minimize the Mean Square Error (MSE) between the actual output of a multi-layer feed forward neural network and the desired output. The block diagram of the Levenberg-Marquardt back propagation neural network algorithm presents in Fig. 1. The following steps give summery of back-propagation algorithm [6]:-

Step 1: Initialize network weight values
Step 2: Sum weighted inputs and apply activation function to compute output of hidden layer

$$h_j = f\left[\sum_i X_i W_{ij} + \theta_j\right] \qquad \text{... (3-1)}$$

Where
h_j: Actual output of hidden neuron j for input signal i.
X_i: Input signal of input neuron (i).
W_{ij}: Synaptic weight between input neuron i and hidden neuron j.
θ_j: is the bias of hidden node j. f: The activation function.
Step 3: Sum weighted output of hidden layer and apply activation function to compute output of output layer.

$$O_k = f\left[\sum_j h_j W_{jk} + \theta_k\right] \qquad \text{... (3-2)}$$

Where
O_k: The actual output of output neuron k. W_{ij}: Synaptic weight between hidden neuron j and output neuron k. θ_k: is the bias of output node k
Step 4: compute back propagation error.

$$\delta_k = (d_k - O_k) f'\left[\sum_j h_j W_{jk}\right] \qquad \text{... (3-3)}$$

Where
δ_k: The error at node k.
f': The derivative of the activation function. d_k: The desired of output neuron k.
Step 5: Calculate weight correction term.

$$\Delta W_{jk}(n) = \eta \delta_k h_j + \alpha \Delta W_{jk}(n-1) \qquad \text{... (3-4)}$$

Where
η: is the learning rate. α: is the momentum coefficient.

Step 6: Sums delta input for each hidden unit and calculate error term.

$$\delta_j = \sum_k \delta_k W_{jk} \; f'\left[\sum_i X_i W_{ij}\right] \qquad \text{... (3-5)}$$

δ_j: The error at node j.

Step 7: Calculate weight correction term.

$$\Delta W_{ij}(n) = \eta \delta_j X_i + \alpha \Delta W_{ij}(n-1) \qquad \text{... (3-6)}$$

Step 8: Update weights.

$$W_{jk}(n+1) = W_{jk}(n) + \Delta W_{jk}(n) \qquad \text{... (3-7)}$$

$$W_{ij}(n+1) = W_{ij}(n) + \Delta W_{ij}(n) \qquad \text{... (3-8)}$$

Step 9: Repeat Step 2 for given number of error.

$$MSE = \frac{1}{2p}\left[\sum_p \sum_k \left(d_k^p - O_k^p\right)^2\right] \qquad \text{... (3-9)}$$

Where

P: The number of patterns in the training set.

Step 10: End.

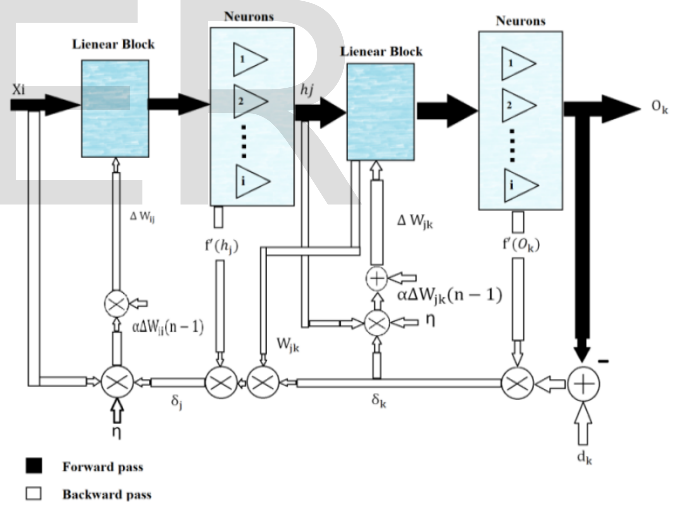

Fig. 1. The block diagram of the back propagation neural network algorithm

2.2 Field Programmable Gate Array (FPGA)

FPGAs are prefabricated silicon devices which can be programmed to produce nearly any type of digital circuit or system. FPGA can perform a variety and different jobs starting from the basic mathematical operations such as addition, subtraction and driving a complex functions in some applications like digital filtering, radar, automobiles and the robotic systems. The basic components of FPGA are; Configurable Logic Block (CLB), programmable interconnects and Input Output Blocks

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(IOBs) as shown in Fig. 2. The large FPGAs can have tens of thousands of CLBs in addition to memory and other resources. Programmable interconnects and CLBs are dominated for FPGA architecture, and CLBs which are relatively simple. This feature makes the FPGAs more flexible in terms of the range of designs that can be implemented with these devices. Fig. 3 presents a simplified FPGA design flow [4].

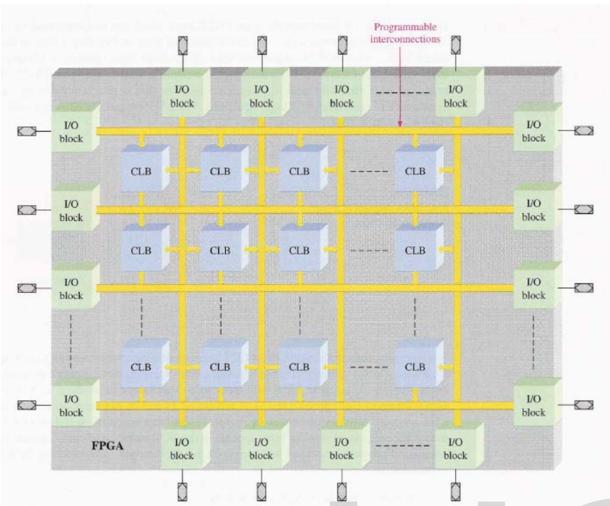

Fig. 2. The basic components of FPGA.

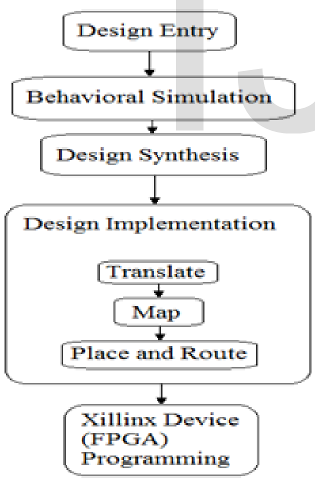

Fig. 3. FPGA design flow.

2.3 Laser Mobile Robot

The navigation of the robot is one of the most important challenges in the domain of mobile robotics as these kinds of robots must be able to evade the obstacles they encounter on their way towards a goal. A mobile robot needs locomotion mechanisms that enable it to move unbounded throughout its environment. There are large variety types of mobile robot. Where it's moving on the ground robots, mobile underwater and flying in the sky, which there types too different in the construction and type of controlling [7].

This paper focus on intelligent control of vehicle navigation, because conventional monitoring techniques are limited due to the uncertainty of the environment where the vehicle is intended to move, therefore, the need to develop intelligent control strategies, such as neural networks because they offer a very good solution to the problem of navigation of vehicles, their ability to learn nonlinear relationships between the input values and sensor values output. In short, the problem is a vehicle located in a particular environment; this environment contains a number of random obstacles and a goal.

3. The Proposed Architecture of FPGA Intelligent Control Mobile Robot

The intelligent controller system used four DC motors to mobile the robot. The On-Off of Robot is started by using laser light and Light Dependences Resistance (LDR) as a sensor, the out from sensors is converted from analog form to digital form by using four ADC0804 ICs. The digital out from sensors will in to the intelligent controller that implemented on FPGA card and the output from the controller will be the inputs for L293D that used as DC motor driver IC. The proposed architecture of FPGA intelligent control mobile robot is shown in Fig. 4. The following subsections illustrate each element in the proposed architecture:-

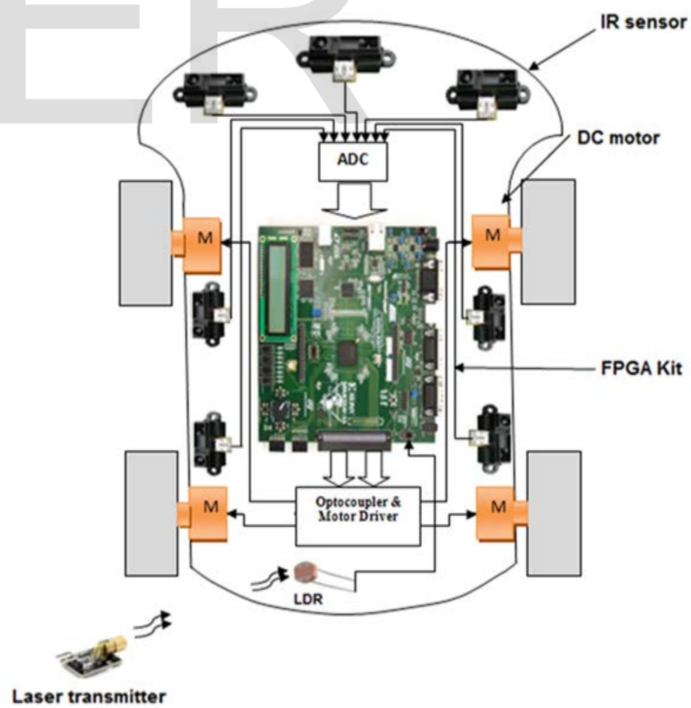

Fig. 4. The proposed architecture of FPGA intelligent control mobile robot.

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3.1 Light Dependent Sensor (LDR)

The LDR sensor is changeable resistance value when it is exposed to light intensity therefore it can be connected in series with a constant resistor in order to do voltage divider with it. Fig. 5 show the LDR sensor connected with constant resistor. The LDR sensors used for sensing the laser light as shown in Fig. 5.

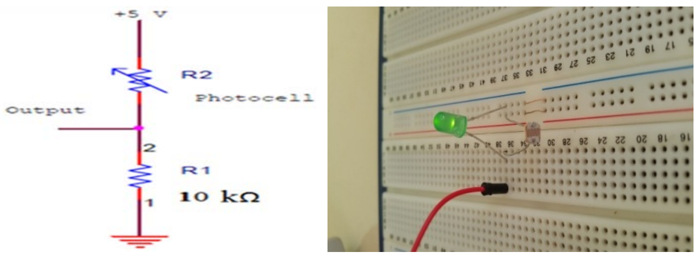

Fig. 5. LDR sensor connected with constant resistor**.**

3.2 Analog to Digital Converter

The LDR sensor output voltage values will be input to the ADC (ADC0804) family is a series of three CMOS 8-bit successive approximation A/D converters using a resistive ladder and capacitive array together with an auto-zero comparator. Fig. 6 show pins diagram for ADC0804 based on data sheet.

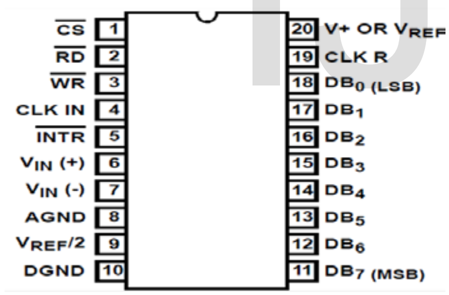

Fig. 6. ADC0804 pins diagram based on data sheet.

3.3 Distance Measuring Sensor Unit (IR)

The distance measuring sensor unit (GP2Y0A21YK0F) is a composed of an integrated combination of PSD (Position Sensitive Detector), IRED (Infrared Emitting Diode) and signal processing circuit as shown in Fig. 7. This device outputs the voltage corresponding to the detection distance. The features of IR sensor for distance measuring range: 10 to 80 cm, consumption current: 30 mA, and supply voltage: 4.5 to 5.5 V based on data sheet.

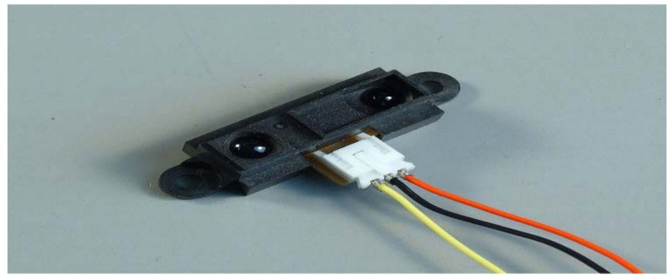

Fig. 7. Distance Measuring Sensor Unit (IR) GP2Y0A21YK0F.

3.4 Laser Transmitter

The Laser transmitter (KY-008) used in robot turn is shown in Fig. 8. Laser Transmitter specifications: The wavelength of 650nm, the color red, the power 5mW, the voltage 5V.

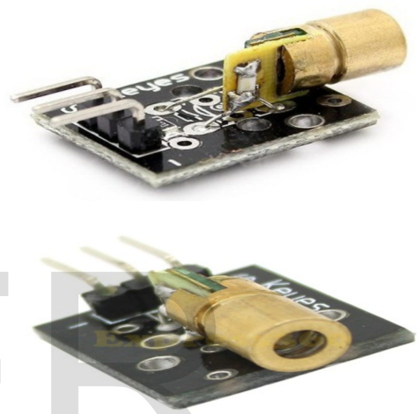

Fig. 8. Laser Transmitter.

4. Simulation Results of Training ANN with BP

In this work, design of intelligent controller is proposed and then downloaded on FPGA board by using VHDL code based on MATLAB package. The ANN is used to control proposed system. The total number of neurons for every hidden layer is different depending on the classification problem. The number of hidden layer and the number of neuron assign based on trial and error. The activation function used to calculate output for each neuron is satlin activation (transfer function equation) except input neuron. The parameters of BP algorithm are set to the momentum coefficient $\alpha = 0.7$ and the learning rate $\eta = 0.4$. The initial weights and biases are randomly generated between [-0.5, 0.5]. In this work an artificial neural networks are designed for each IR sensor. Matlab simulation training for a proposed ANN. Training the ANN by Matlab 2013a and the MSE curve illustrated in Fig. 9 and Fig. 10. Fig.11 shows the Matlab simulation for the complete networks of seven IR sensors used in laser mobile robot.

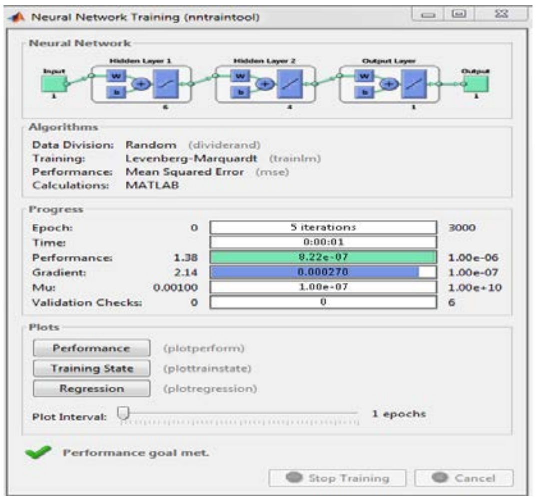

Fig. 9. Training the network by Matlab 2013a.

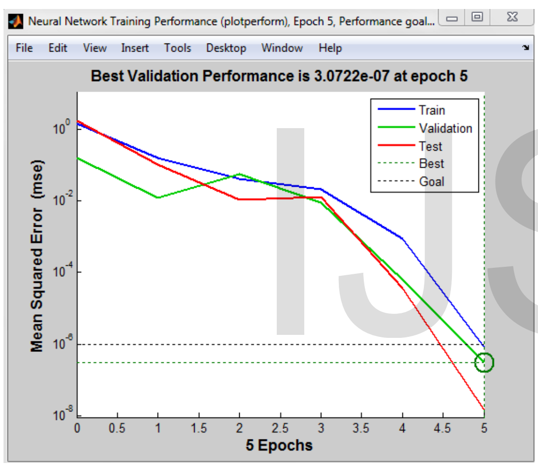

Fig. 10. Matlab simulation training for ANN.

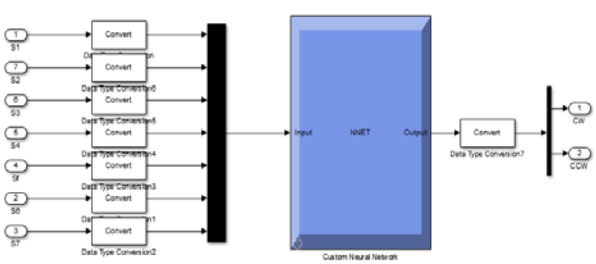

Fig. 11. The complete network of 7 IR sensors.

5. Experimental Results

The implementation of intelligent controller on FPGA Xilinx Foundation ISE design suite 13.3 is a software tool used to perform ANN for mobile robot controller on FPGA. After the mobile robot controller signal generated, it's time to observe the output and see if the experimental result goes the same way as the simulation result and this achieved in Fig. 12 and Fig. 13 for simulation and experimental results.

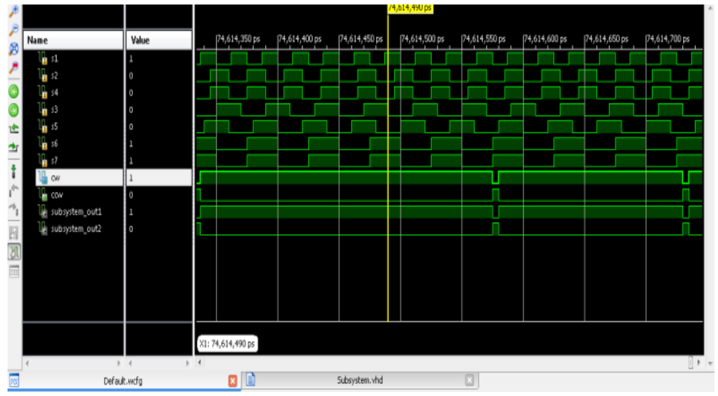

Fig. 12. FPGA Xilinx simulation results for implementation of intelligent controller.

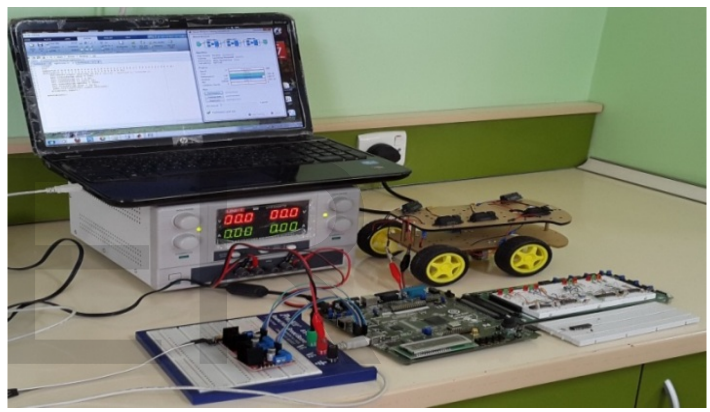

Fig. 13. Experimental result of laser Mobile robot based on Xilinx FPGA simulation.

6. Conclusions

This paper presents the system of predictive robot by using intelligent systems, IR sensors and embedded the laser technology in the control which gives flexible in turning ON or OFF with a remote system. Xilinx FPGA board and neural controller have been used as a main processing unit of all the operation in the system which provides high efficiency and excellent possibilities in processing information and gives the suitable order to avoid obstacles in exact time. IR sensors utilize to locate the obstacles to avoid them by control on the speed and direction of DC motors. The proposed controller was implementing on FPGA Xilinx Spartan 3 board and used to mobile the robot by using four DC motors provided with gearbox. The use of DC motor enables accurate speed depending on the speed of the FPGA card. LDR resistor is oriented to determine the laser light intensity in all directions. This controller has been tested for different data by using Matlab/Simulink program.

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