FPGA Realization of Mobile Robot Controller using Fuzzy Algorithm

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Abstract: - This paper describes a Fuzzy Logic Controller (FLC) algorithm for designing an autonomous mobile robot controller (MRC). The controller enables the robot to navigate in an unstructured environment and that avoid any encountered obstacles without human intervention. The autonomous mobile robot is found to be able to react to the environment appropriately during its navigation to avoid crashing with obstacles by turning to the proper angle while moving. The Fuzzy Logic algorithm has proven a commendable solution in dealing with certain control problems when the situation is ambiguous. One of the main difficulties faced by conventional control systems is the inability to operate in a condition with incomplete and imprecise information. As the complexity of a situation increases, a traditional mathematical model will be difficult if not impossible to implement. Fuzzy Logic is a tool for modeling uncertain systems by facilitating common sense reasoning in decision-making in the absence of complete and precise information. In this paper, the controller of an autonomous mobile robot is designed based on the theories of Fuzzy algorithm. The wheeled robot is able to navigate by itself in a completely unstructured environment. The codes of MRC has written for implementing the separate modules of the Fuzzifier, Fuzzy Rule Base, Inference mechanism and Defuzzifier as hardware blocks.

A behavioral model of MRC algorithm is first developed in MATLAB platform with numerous data to evaluate its algorithm functionality. The development of MATLAB codes has converted into VHDL codes for hardware implementation. Comparison results between MATLAB and VHDL of MRC algorithm also have presented. Then the VHDL codes are synthesized to get MRC hardware blocks using synthesis tool, Quartus II from Altera environment. Finally the designed codes of MRC algorithm has been downloaded into FPGA board for verifying the functionality of algorithm for VLSI implementation.

Key-Words: - Fuzzy rules, Mobile Robot Controller, Navigation algorithm, VHDL, Synthesis, FPGA

1 Introduction

Uncertain environments with incomplete and imprecise information pose fundamental difficulties to conventional control systems. In this case, the feasibility of applying Fuzzy logic to facilitate common sense reasoning in decision-makings to counter such problems. One of the main difficulties is faced by conventional control systems are the inability to operate in a condition with incomplete and imprecise information. As the complexity of a situation increases, a traditional mathematical model will be difficult for implementing the process. Fuzzy Logic is a tool for modeling uncertain systems by facilitating common sense reasoning in decision-making in the absence of complete and precise information [1-3]. It enables the arrival of a definite conclusion based on input information, which is vague, ambiguous, noisy and inaccurate.

In this paper, the controller of an autonomous mobile robot has designed based on the theories of Fuzzy Logic [4-5]. The wheeled robot is able to navigate by itself in a completely unstructured environment. The FLC receives limited information of the environment through sensors, and decides an appropriate angle to turn while it moves with constant velocity to avoid any objects within its vicinity. The main focus is to develop the modeling of Fuzzy rule based algorithm for MRC and realize its hardware functionality using FPGA board.

On top of this paper it introduces the FLC algorithm and after this part this papers describes briefly the modeling of mobile robot controller with Navigation Algorithm (NA). VHDL modeling and Synthesis are describes after the matlab simulation respectively. Besides conclusion, this paper ending with FPGA realization and the real life application of fuzzy based MRC.

2 Modeling of MRC With NA

The MRC monitored by the Fuzzy Logic algorithm for navigating through an unstructured environment without human intervention [6-7]. In this process of moving from one place to another, it is necessary for the robot to have information on its current position, where the intake of this vital information is through the two sensors on its body. Fig.1 shows the physical modeling of the MRC.

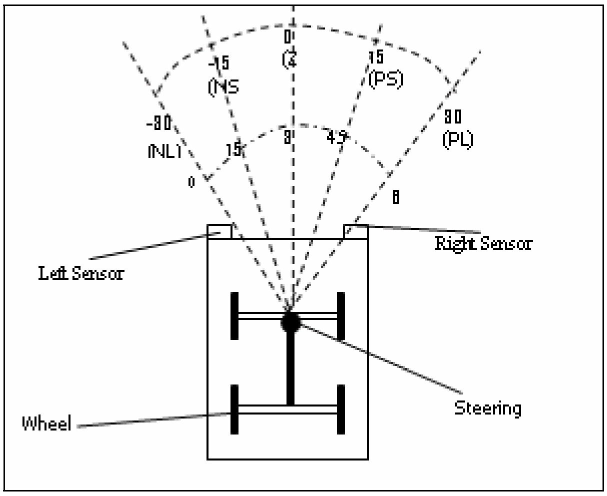

Fig.1 Modeling of the MRC

As an example, the Mobile Robot resembles of a car, in which navigation is made possible by four wheels, controlled by the steering. A significant difference of steering is controlled by the FLC instead of human intelligence. The sensors are positioned in such a way that the robot is able to detect its distance from obstacles, one from its left and another from its right. The steering has a maximum turning angle of 30 degrees. It should be noted that the robot moves in a constant velocity and the only variable controlled by the FLC is the orientation of the robot (the steering angle, in degrees).

The FLC receives two inputs pattern, one from the Front Left Sensor, and another from the Front Right Sensor. The inputs are measured in distance. The output is an orientation of the steering, measured in degrees.

2.1 Inputs pattern

The inputs from both the sensors measures distance by a numerical value ranging from 0 to 40. An input of "0" denotes the minimum possible distance, which can be detected, where the robot almost or actually touches the obstacle. An input of "40" denotes the maximum distance as the obstacle is either far away from the robot's vicinity or could not be sensed at all.

2.2 Output pattern

Referring to Fig.1, the Figure shows that the robot is capable of turning an angle of -30 to 30 degrees. However, the output of the FLC, like the inputs is also a numerical value, ranging from 0 to 60. The 0 value represents -30 degrees while "60" represents 30 degrees.

In short, the input parameter for both the left and right sensors is the linguistic variable distance, while the output parameter is the linguistic variable angle. They are modeled by the following sets:

Distance1(left sensor)*A = { A1,........,A3} = { far, near, vnear}*

Distance2 (right sensor)$\cong$ *B ={B1,........,B3} = { far, near, vnear }*

Angle $\cong$ *C = {C1……..,C6} = { NL, NS, Z, PS, PL }*

Both input and output membership functions are identical which has shown in Fig.2 & Fig.3 respectively.

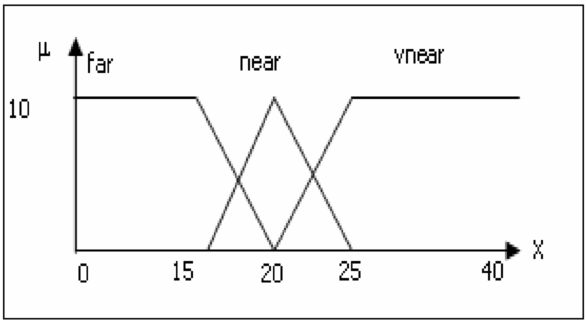

Fig.2 Left & right sensor input Membership function.

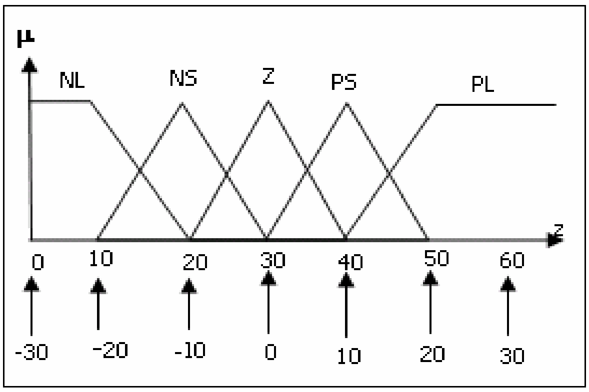

Fig.3 Output membership function

The navigation of the mobile robot is fairly simple. "Structure of the Mobile Robot" and "Fuzzy Logic Controller Architecture" has generally given an idea of the movements of the robot. The sensors are the “eyes” of the robot. They give information on how far the robot is from an object. The FLC is its “brain”. It decides on which angle to turn in order to avoid those obstacles.

The FLC takes in a crisp input from each of the sensors. The Fuzzifier categories focus the inputs into Fuzzy sets according to the input membership function. The Rule Base determines the behavior of the robot and decisions are made depending on the rules. The Inference Engine determines rule at a specific situation. The Deffuzifier converts the decision made according to the rule-base, which is in Fuzzy terms, into a crisp output. The output is an orientation of the robot (decides which angle to turn). Algorithmic flow chart is shown in Fig.4.

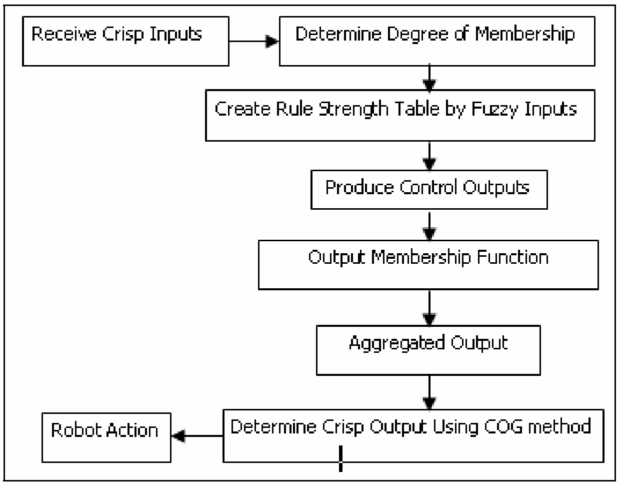

Fig.4 Flow chart of MRC algorithm

Finally, the FLC gathers information through its sensors, and decides on an action (the output) which is the turning angle of the robot to avoid the obstacles. In fact, after the intake of information (numerical values) through the sensors, fuzzification takes. The values into linguistic variables (far, near, very near), using the input membership functions. Decisions will be made complying to a Rule Base, the rules decides on each situation, to take an action of either giving the robot a “negative large (NL)”, “negative small (NS)”, “zero”, positive small (PS)” or “positive large (PL)” orientation. This is yet not the end of the process because the system requires an exact value as an output, a crisp output. This is achieved by Defuzzification, applied on the output membership function. An autonomous mobile robot is responsible of navigating by itself without human intervention (remote controller etc.). This is achieved using a FLC Algorithm. The computed MRC block diagram using FLC algorithm is shown in Fig.5.

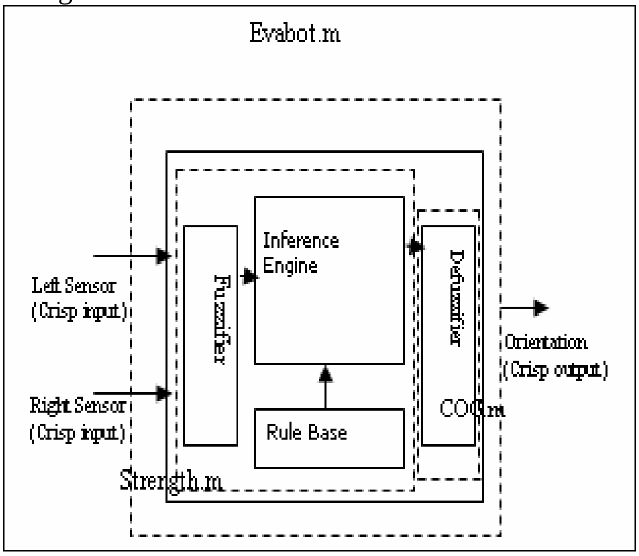

Fig.5 FLC block diagram

3 MATLAB SIMULATION

The simulation result in MATLAB is partially graphical part, which consist of the graphs that show the shape of the input membership functions (one for the left sensor and another for the right sensor), the graph that shows the shape of the output membership function, and lastly the graph that shows the aggregated output (final output). The more important part of the result is the values computed for: i) degree of membership ii) Rule Strengths iii) Aggregated Output (this is the final output, which is the orientation of the robot in degrees). To obtain a crisp output using COG method are given below.

AGG(i) = max([min([cut1 Z(i)]) min([cut2 NS(i)]) min([cut3 NL(i)]) min([cut4 PS(i)]) min([cut5 Z(i)]) min([cut6 NS(i)]) min([cut7 PL(i)]) min([cut8 PS(i)]) min([cut9 Z(i)])]);
den = den + AGG(i);
num = num + i*AGG(i);
output = num/den

In the above equation, the control outputs are obtained. Here “den” denotes the denominator of the COG equation while “num” denotes the numerator. Dividing “num” by “den” produces the final output. For different case of navigating the robot, the controller takes input, such as left sensor (LS) and Right sensor (RS) for different foreseen situation. Finally, the simulation results are given in Table 1.

Table 1: Simulation result of robot control using MATLAB

Case 1 LS=0 RS=0	Case 2 LS=16 RS=21	Case 3 LS=21 RS=16	Case 4 LS=10 RS=35	Case 5 LS=35 RS=10
Y=10,0,0	Y=8,2,0	Y=0,8,2	Y=10,0,0	Y=0,0,10
Z=10,0,0	Z=0,8,2	Z=8,2,0	Z=0,0,10	Z=10,0,0
S1=0	S1=0	S1=0	S1=0	S1=0
S2=0	S2=8	S2=0	S2=0	S2=0
S3=0	S3=2	S3=0	S3=10	S3=0
S4=0	S4=0	S4=9	S4=0	S4=0
S5=0	S5=2	S5=2	S5=0	S5=0
S6=0	S6=2	S6=0	S6=0	S6=0
S7=0	S7=0	S7=2	S7=0	S7=0
S8=0	S8=0	S8=2	S8=0	S8=0
S9=0	S9=0	S9=0	S9=0	S9=0
num=3100	num=2860	Num=5758	Num=1320	num=8290
den=100	den=139	Den=139	Den=155	den=155
ans=31	ans=20.5755	Ans=41.4245	Ans=8.5161	ans=53.4839

4 VHDL MODELING

The structures of MRC in MATLAB plateform consist of three modules (evabot.m, strength.m and COG.m) are implemented in VHDL as evabot.vhd, STR3.vhd, and COG.vhd respectively.

The modules are combined to form the structure of the MRC controller which is shown in Fig.6.

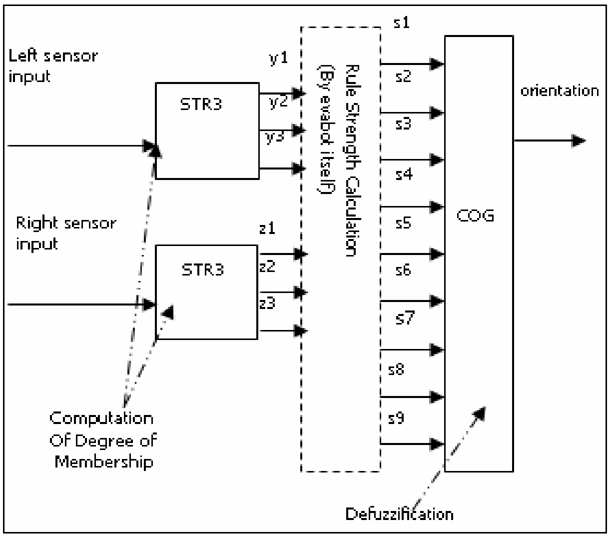

Fig.6 Design Structure in VHDL

The two STR3 modules separately receives one external input each and produces the degree of membership as y1,y2,y3 and z1,z2,z3. The "rule strengths" are produces by the evabot itself, as s1, s2, s3, s4, s5, s6, s7, s8 and s9 as internal signals. These are sent to COG for defuzzification and the final output is produced as the orientation of the robot.

For each of the cases, it is observed that the "degree of membership" and the "rule strengths" obtained from VHDL simulation is exactly almost same values which are obtained in MATLAB simulation is shown in Table 2. The VHDL simulator is also generate Register Transfer Level (RTL) block of MRC which consists of hardware blocks to verify the MRC behavirioul level of algorithm.

Table 2: Comparison Results

Foreseen situation	VHDL	MATLAB
Case 1 (0,0)	31	31
Case 2 (16,21)	20	20.5755
Case 3 (21,16)	41	41.4245
Case 4 (10,35)	8	8.5161
Case 5 (35,10)	53	53.4839

5 SYNTHESIS

Synthesis is the process of transforming one representation in the design abstraction hierarchy to another representation. Synthesis process has performed using synplify tools for synthesizing the compiled VHDL design codes into gate level schematics.

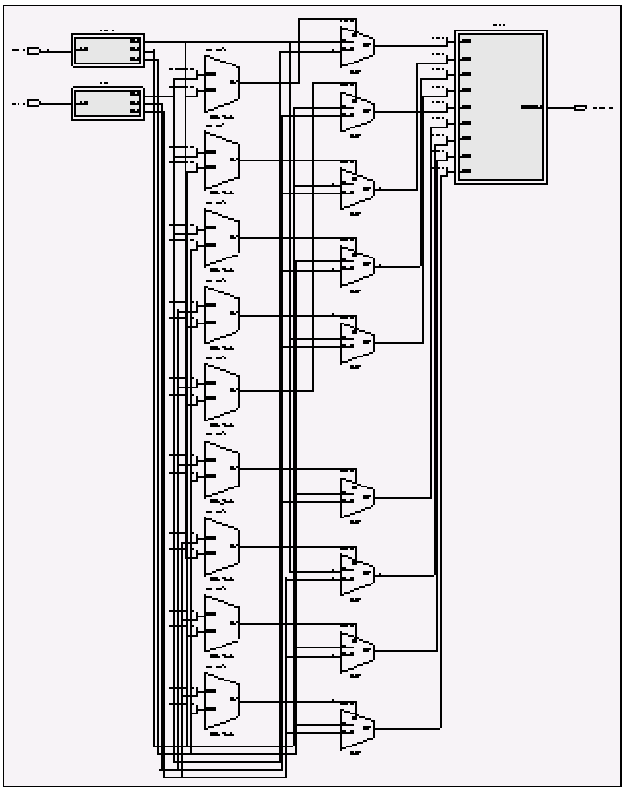

Fig.7 RTL View of MRC blocks.

In order to get the Register Transfer level (RTL) view of MRC architecture, the VHDL codes are synthesized. The Technology mapping has chosen in this project from Altera's FLEK10K70. Then the technology view of the various modules for MRC chip has been carried out. As an example, the top level of RTL views of the MRC is shown in Fig.7. The flattened technology view of sub-hardware blocks of STR3 and COG for MRC chip is shown in Fig.8 and Fig.9 respectively. Finally the synthesized tool has downloaded into FPGA board for testing its algorithmic functionality.

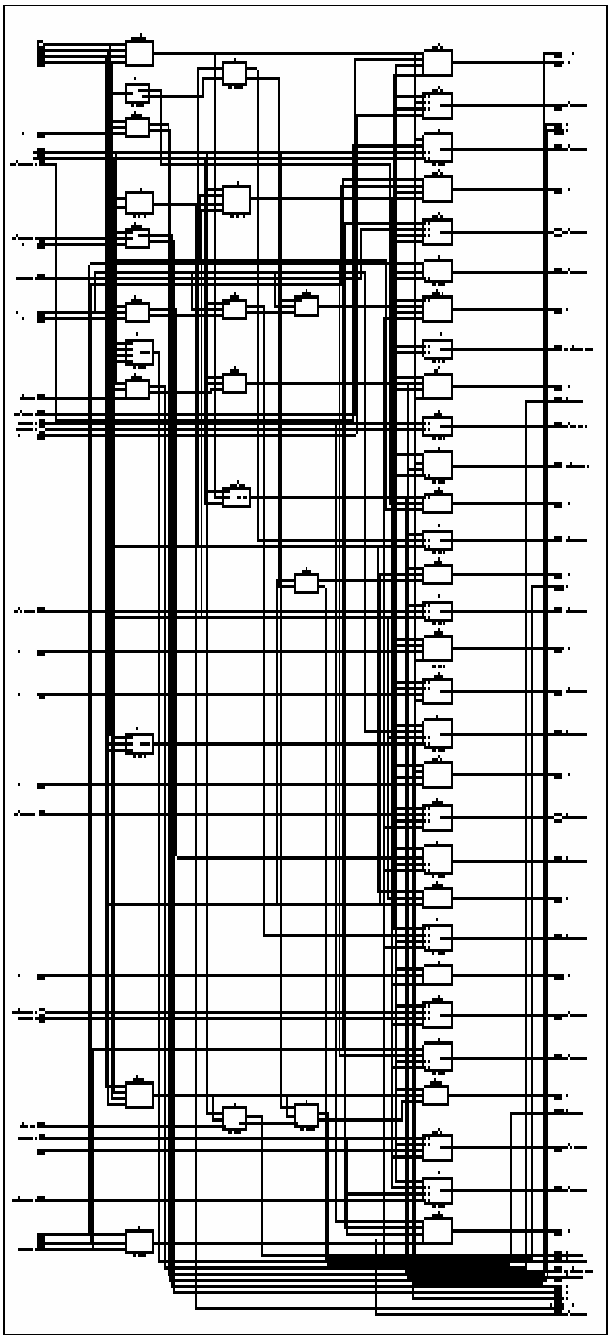

Fig.8 Technology Map View of STR3

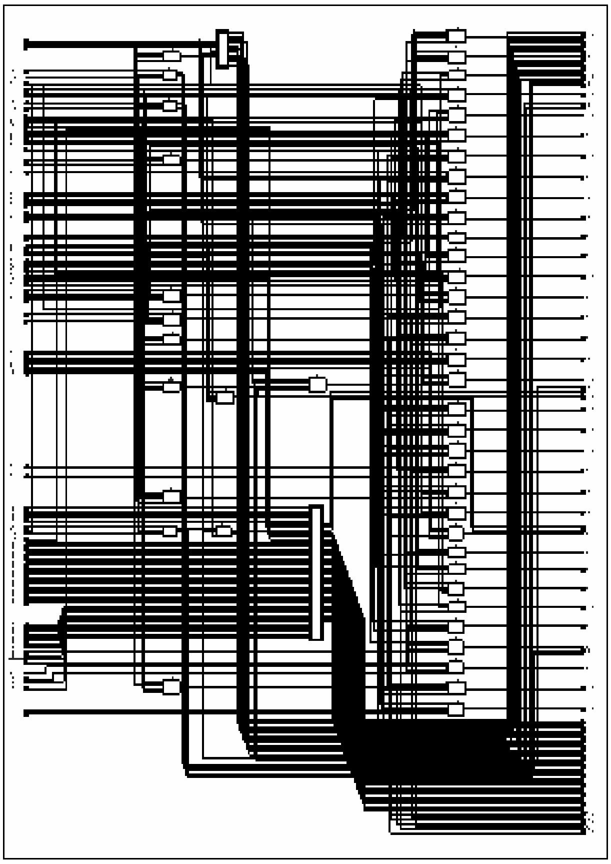

Fig.9 Technology Map View of COG

The Timing Analyzer in Fig.10 shows the delay of design path and reports the performance of the design in terms of maximum clock speed (fMAX). From the report, it is observed that the longest delay is 46.13ns from a source register to a destination register in STR3. Hence, the maximum clock speed, fMAX is 21.68MHz. Setting the hardware working frequency with 20MHz, the circuit will be confirmed reliability.

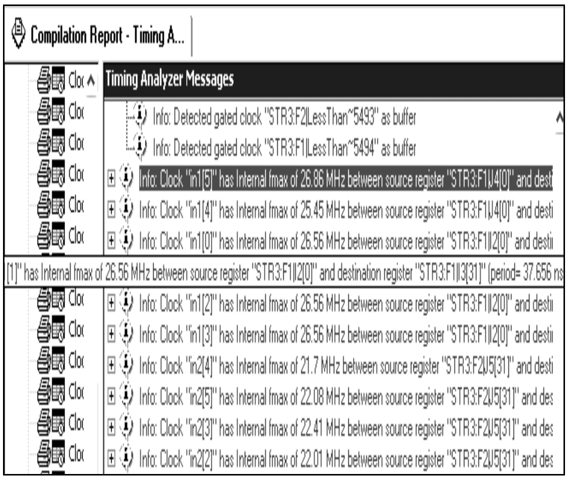

Fig.10 Timing Analyzer Report

6 FPGA Realization

This section focuses on the implementation of the MRC algorithm using FLEX10K device using in UP1 Educational Board. During the implementation step, the design codes of the Controller have downloaded into Altera APEX 20K200EF484 FPGA board as shown in the Fig.11.

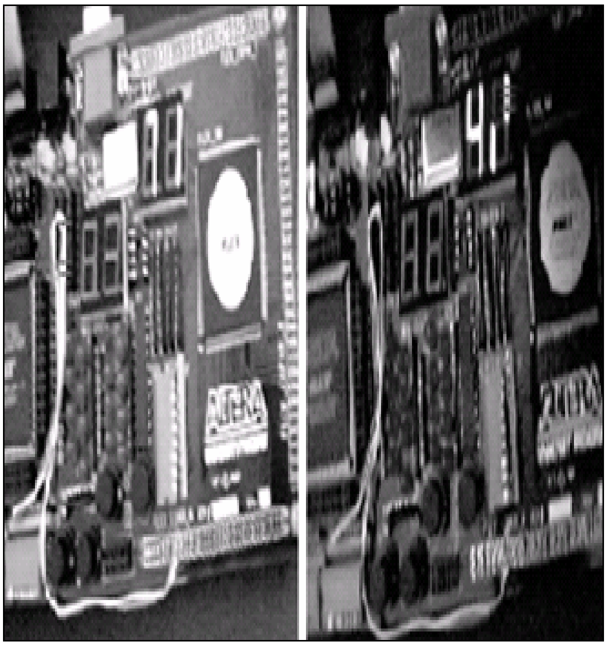

Fig.11 Downloaded into FPGA board

7 Application

Generally mobile robots have the capability to move one place to another place in their environment and are not fixed to one physical location. The most common class of mobile robots is wheeled robots. Other classes of mobile robots are legged robots, aerial robots and autonomous underwater vehicle type robot. All these four types of mobile robots share several unfavorable features such as reaction with unplanned situation, energy autonomy and reaction after getting stuck.

Conventional MRC are not capable to improve there behaviors by modifying internal control parameters based on experienced situations. As for example, Neural networks, and Genetic algorithmic approaches also do not offer yet enough guarantee of stability in unsupervised situations for being accepted as a viable method in critical applications where risks and costs rank high.

In this paper, our proposed MRC chip can be used in any kind of environment by which we can get an improvement of relative performance with respect to the conventional scheme. It shows better performance during unplanned situation. As for example after getting stuck, the MRC chip by using navigation algorithm can able to find out a way without human intervention. So this kind of MRC can be used widely and efficiently in searching antipersonnel landmines. This MRC chip can be used on vacuum cleaning of sensitive area where human can not reach and it can be able to show a dramatic performance if used in the vehicle for handicap people.

8 Conclusion

The design step of MRC has successfully presented in this paper using navigation algorithm based on Fuzzy logic algorithm. The constructed MRC has simulated with MATLAB platform. The MRC algorithm in MATLAB has been translated into VHDL codes and then synthesized it to design MRC functional hardware blocks for VLSI implementation. Finally the designed synthesized codes have downloaded into FPGA board for testing the MRC algorithm functionality. The results show that the robot reacts accordingly to the environment. It turns to the appropriate angle to avoid obstacle within its vicinity while navigating the completely unstructured environment.

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