Fuzzy based PID Controller using VHDL for Transportation Application

Md.Shabiul Islam ,Nowshad Amin , Mukter Zaman , M.S.Bhuyan

***Abstract*—** This paper describes the designing of PID-type (Proportional-Integral-Derivative) controller based on Fuzzy algorithm using VHDL to use in transportation cruising system. The cruising system with Fuzzy concept has developed to avoid the collisions between vehicles on the road. The developed Fuzzy Logic Controller (FLC) provides a reference for controlling the vehicle speed either increase or decrease. The controlling speed depends on the distance of the preceding vehicle when it gets too close or alert the driver when necessary. The Mamdani Fuzzy Inference theory is studied, and developed in Matlab package at first for designing the PID-type FLC hardware system. The behavioral of the PID-type FLC algorithm is then simulated using VHDL language. The comparison of simulation results between Matlab and VHDL are presented for designing the PID-type hardware implementation. The synthesis tool from Quartus-II environment is chosen to synthesize the designed VHDL codes for obtaining the Register Transfer Level (RTL) hardware architecture of the PID modulus. The developed and designed Fuzzy based PID-type cruising controller is cheaper in cost compare to conventional PID controller system, and, thus we can propose this developed chip to use to the entry-level vehicles such as the national car. This can be further reduced the road accident and ensure the safety of the road users in the future.

***Keywords*—**PID algorithm, VHDL, Fuzzy, Synthesis.

I. INTRODUCTION

PID controller is the best known as industrial process controller [1]. It is robust in wide range of performance [2]. However, conventional PID controller is not suitable for non-linear system [3]. Therefore, PID-type Fuzzy Controller is preferred in the non-linear process due to its simplicity, robustness, and variable structure. Moreover, the PID controller does not require explicit knowledge of the model of the dynamic plant, which is complex and very hard to obtain. The PID controller mostly can be applied to the control process such as motor drives, flight controls, high-speed trains, and others application. Improvement on the PID controller system can lead to huge effect in the control process for industrial application. Therefore, the PID-type Fuzzy controller system is investigated, design and simulated in this project.

Fuzzy system is well known with its non-linearity characteristic behavior [4]. Therefore, the non-linear characteristic of the conventional PID controller can be improved greatly using fuzzy logic algorithm. Besides, most of the research works have done on the Fuzzy PID controller, which are, focusing on the conventional two-input PI (Proportional-Integral) or PD (Proportional-Derivative) type as proposed by Mamdani [5]. This is because the three-inputs of PID controller are a complex task, as more parameters have to be considered in building the fuzzy rule base [6]. It is difficult to determine the control rules for the Integral mode input ($\sum e$), as the steady state error of a system is very hard to define [6]. Therefore, the three inputs of the controller are defined as error (e), change in error (Δe) (also known as Derivative), and the rate of change of error ($\Delta 2e$) (also known as acceleration error), [6]. Besides it, there is no proper way of tuning method available until now. Trial-and-error tuning method is required in optimizing the controller [7]. Furthermore, the number of rule base increase exponentially with the increase of membership function [7]. If the number of input is m, and the number of membership function for each input is n, then the total number of the IF-Else rules is equal to mn.

The rest of the paper is organized as follows: Section 2 describes the PID type fuzzy controller algorithm. Section 3 presents the MATLAB simulation result. Modeling of the controller using VHDL is described in section 4. Section 5 presents the comparisons between MATLAB and VHDL simulation results. Section 6 presents the Synthesis. Section 7 presents PID controller application. Finally, conclusion is drawn in this paper.

II. PID CONTROLLER WITH FUZZY ALGORITHM

The Fig. 1 shows the flow chart of PID-type fuzzy controller algorithm for implementing PID-type FLC hardware design. The crisp inputs of the PID fuzzy controller have computed in MATLAB platform [8].

In this simulation stage the membership function of the controller is shifted 20 steps to the positive side and the setpoint is 20 (actual setpoint = 0). Therefore, the crisp input is shifted 20 steps towards the positive side as well. As an

Manuscript received June 6, 2007: Revised version received April 6, 2008.

Md. Shabiul Islam, is with the Faculty of Engineering, Multimedia University, 63100 Cyberjaya, Malaysia, (corresponding author : +603-8312 5380; e-mail: shabiul@mmu.edu.my)

Nowshad Amin., is with the Department of Electrical, Electronic and System Engineering, Faculty of Engineering, National University of Malaysia, 43600 UKM, Bangi, Selangor, Malaysia. (e-mail: nowshad@vlsi.eng.ukm.my).

Mukter Zaman is with the Faculty of Engineering, Multimedia University, 63100 Cyberjaya, Malaysia (corresponding author : +603-8312 5380; e-mail: mukter.zaman@mimos.my

M.S.Bhuyan is with the Faculty of Engineering, Multimedia University, 63100 Cyberjaya, Malaysia (e-mail: shakir_dhaka@yahoo.com)..

example of the input of -6, the input read by the controller is (-6 + 20) = 14. Fig. 2 shows the Input and output membership function of PID-type Fuzzy Controller.

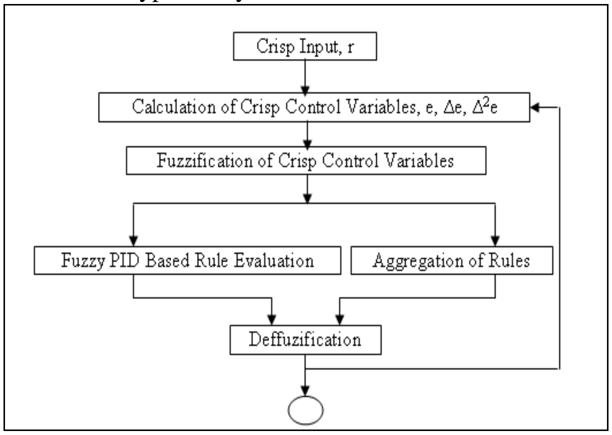

Fig. 1 Flow chart of PID-type fuzzy controller algorithm.

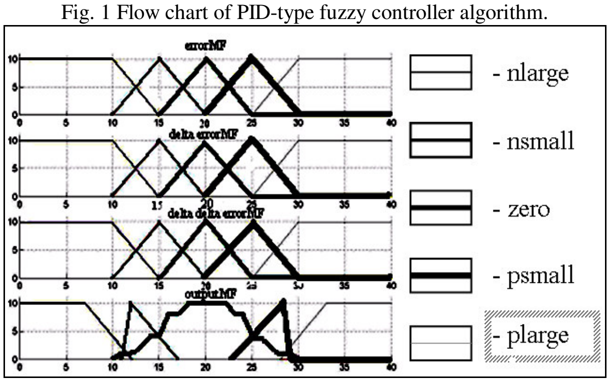

Fig. 2 Inputs and output membership function of PID-type Fuzzy Controller

The three inputs of the Fuzzy PID controller are calculated for the following variable stages:

1. Error input = crisp input
2. Delta error input = current error - previous error
3. Delta^2 error input = current delta error - previous delta error

III. MATLAB SIMULATION RESULTS

Fig. 3 shows the MATLAB simulation result for error (e), delta error (Δe), and delta^2 error (Δ^2e). From the complete simulation result of error (e), it can be observed that the value of error is reduced to zero when the Fuzzy process is further applied to the outputs.

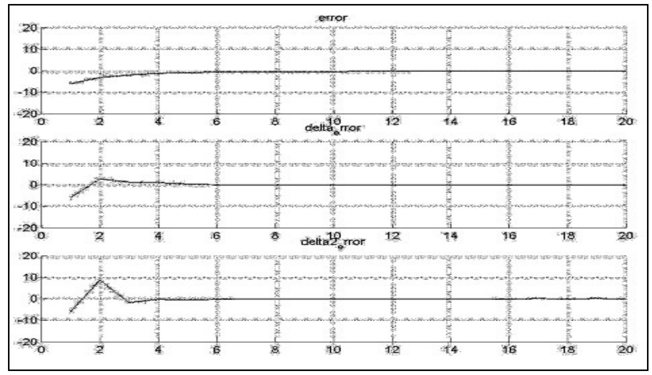

Fig. 3 MATLAB simulation result, initial error = -6

IV. MODELING OF PID CONTROLLER USING VHDL

The behavior of PID-type Fuzzy controller algorithm for designing a hardware system has developed using VHDL language. The developed code in VHDL is used to perform four Mamdani Fuzzy interface processes as well. In this step, there are six modules of PID controller (i. Fuzzification: degree_truth.vhd, and cutMF.vhd, ii. Rule Evaluation: rule_base.vhd, and rule_degree.vhd, iii. Aggregation ruls and Defuzzification: COG.vhd, and iv. one variable calculation: var_cal.vhd) block have been carried out for implementing hardware design. The above six modules are combined together into the controller unit (controller.vhd) to perform the four Mamdani Fuzzy Inference processes. The var_cal.vhd module is used to calculate the three crisps inputs of the PID-type Fuzzy Controller System.

The Current_delta_error is equal to the difference between the input and old_error pins whereas the Current_delta^2_error is equal to the difference between the old_error and the old_delta_error. Next, this module will be feedback the Next_old_error and Next_delta_old_error output to Old_error and Old_delta_error at the input respectively for the variable calculation operation.

The Fuzzification steps have computed with three crisp inputs using the degree_truth.vhd and cutMF.vhd module to perform the fuzzification task.The degree_truth.vhd module is determined the input membership function based on crisp input. On the other hand, cutMF.vhd module determines the input membership function that involves corresponding to each of the degree oftruth. Table 1 shows the output of each of the degree_truth.vhd and cutMF.vhd.

Table 1: Output of each of the degree_truth.vhd and cutMF.vhd 1

Module	Output of *degree_truth.vhd*	Output of *cutMF.vhd*
1	D1, D2	M1, M2
2	D3, D4	M3, M4
3	D5, D6	M5, M6

The rule_based.vhd module is used to determine the output membership function on its input membership function from cutMF.vhd module. Since the total number of rules involve is equal to 2^3 = 8, therefore eight rule_based.vhd modules is needed to perform each of the rule base operation. Besides, the degree of truth of the input membership function found by degree_truth.vhd module is “anded” together to obtain the minimum value of output membership function. Table 2 shows the complete operation of rule_base.vhd and rule_degree.vhd in each fuzzy inference cycle.

Table 2: Complete operation of rule_based.vhd modules in each fuzzy inference cycle.

Rule_base Module	Involved Input membership function	Output membership function	Degree of truth of output membership function
1	M1, M3,M5	B1	Min(D1,D3,D5)
2	M1, M3,M6	B2	Min(D1,D3,D6)
3	M1, M4,M5	B3	Min(D1,D4,D5)
4	M1, M4,M6	B4	Min(D1,D4,D6)
5	M2,M3,M5	B5	Min(D2,D3,D5)
6	M2, M3,M6	B6	Min(D2,D4,D6)
7	M2, M4,M5	B7	Min(D2,D4,D5)
8	M2, M4,M6	B8	Min(D2,D4,D6)

Finally, the COG.vhd module is operates based on Aggregation of Rules and Defuzzification accordingly. In aggregation rule, all the output of rule evaluation is combined to form a single Fuzzy set. The output of aggregation of rules is a set of possible crisp output. However, a unique value is needed to be determined at the final output of the controller.

The COG is used in the defuzzification process. The centroid is determined by using the PID algorithm. All the suggested above modules are combined together to form PID-type fuzzy controller system (controller.vhd) for hardware implementation in next step.

The three inputs of input_c, old_error, and old delta are considered the inputs of the PID-type Fuzzy controller system as same as the PID controller inputs of error (e), delta error (Δe), and delta^2 error (Δ^2e) respectively. The output_c is the output of the controller that represents the new error after the Fuzzy Inference processes. Nex_error and nex_delta is the current error and delta error value, which will be fed back to old error and old delta error respectively for the next controller operation. The Num_c and den_c are for monitor purposes only, which allows the output of Aggregation of Rules of each cycle for calculating manually. Besides it, the output_c is plotted to obtain the graphical view of the operation of the PID controller system.

The VHDL algorithm successfully reduces the error to the setpoint (zero) which fulfils the specification as the PID-type Fuzzy controller system. The VHDL simulation results is given in the next section 5.

V. Comparison results in MATLAB and VHDL

Both the MATLAB and VHDL simulation results meet the specification of PID-type FLC system for designing VLSI chip and the algorithm is also reduces the error to zero. However, the algorithm takes the different paths to achieve the zero point. Fig. 4 and Fig. 5 shows the VHDL simulation plots and matlab to compare their coefficient respectively.

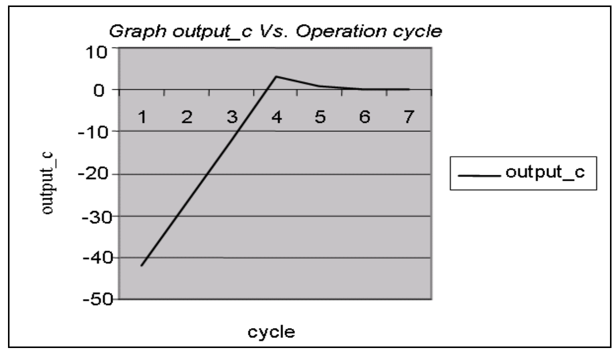

Fig. 4 VHDL simulation plot for initial error = -42

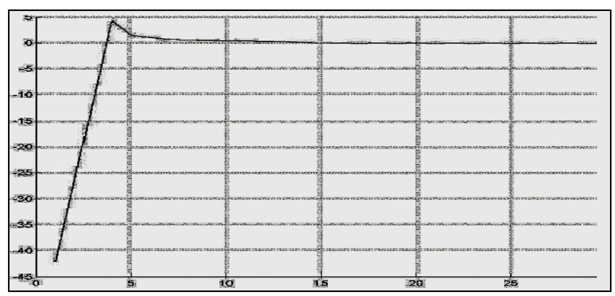

Fig. 5 MATLAB simulation plot for initial error = -42

VI. Synthesis

Synthesis is the process of transforming one representation in the design abstraction hierarchy to another representation. Synthesis process has performed using synthesis tools (Quartus II) for synthesizing the compiled VHDL design codes into gate level schematics. It initially processes the VHDL building blocks to Register Transfer Level (RTL) block for all six hardware modules of PID controller system. The components of modules are such as multiplier, registers, gates and flip-flops etc. While synthesizing the design, HDL library browser was used to synthesize the design in a hierarchical manner. In this paper, we have presented one of the RTL blocks among of six modules. The RTL view of PID-type Fuzzy controller system is shown in Fig. 6.

Next, the Technology mapping step has been performed using Altera’s APEX20KE (EP20K200EFC484-2X) package to get the technology view of the various modules of PID-type Fuzzy Controller chip. As an example, one of technology views of the PID-type Fuzzy Controller modules system is shown in Fig. 7.

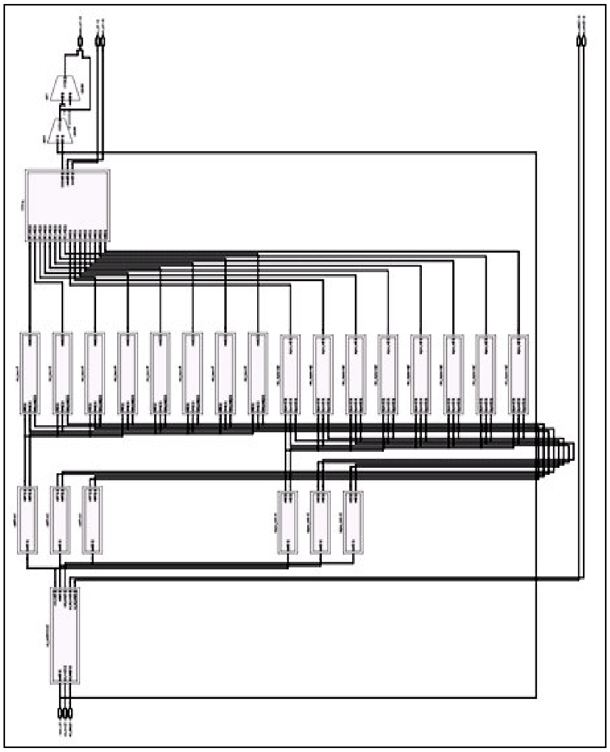

Fig. 6: RTL view of PID-type Fuzzy Controller System

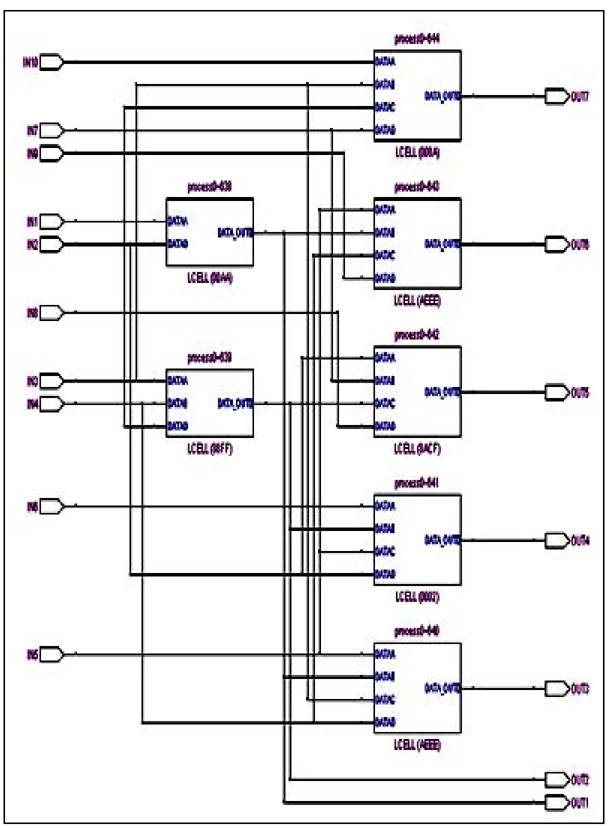

Fig. 7: Technology View of PID-type Fuzzy controller System. (Var_cal module)

VII. Application

The targeted application of the Fuzzy based PID controller in this work is the transportation cruising system. The cruising system that developed is to avoid the collision between vehicles on the road. The system sense the distance of the preceding vehicle and reduce the speed when it get too close or alert the driver when necessary. Besides, it also limits the acceleration of the vehicle depending on the distance of the preceding vehicle.

This system is being developed by Mercedes Benz and is installed in its new line of S-Class. However, the technology developed is expensive as the radar system and image processing is involved. Therefore, only the luxury cars can enjoy such accessory. The Fuzzy based PID cruising controller that developed in this work is cheaper and can be applied to the entry level vehicles such as the national car. This can further reduce the road accident and ensure the safety of the road user in the future.

The output of the PID-type Fuzzy Controller provides a reference for a car to either increase or decrease the speed of the vehicle. For example, if the set-point is 20 unit of distance, then the car will be slow down if the distance of the preceding vehicle is below 20 units of distance. If the distance is above 20 unit of distance, then the vehicle is allowed to accelerate. However, the rate of acceleration and deceleration is depending on the distance of the vehicle. By referring in Fig.8, the rate of deceleration and allowed acceleration is depends on the distance of the vehicles. When the two vehicles is too near to each other, which is below 10 units of distance, the controller will give medium force in decelerating the vehicle and at the same time, alert and warn the driver to apply the brakes for urgent braking. This is to ensure the safety of the passengers instead of giving hard stop to the vehicle which may injure the passenger due to the sudden momentum.

VIII. Conclusion

The PID type fuzzy controller algorithm has described first using MATLAB platform. The described PID controller also has developed with all fuzzy rules for designing the hardware PID chip using VHDL. Then, the synthesize tool has used to get the logic gates of hardware PID modules. The designed PID chip can be used to the targeted application. As an example, transportation cruising system. The cruising system based on PID chip can be avoided the collision between vehicles on the road

The controller algorithm will be further optimized by improving the membership function, the rule base, and the tuning method. It should be done to obtain better control over its application because there are many constraints those needs to be considered in the real world and to ensure the safety of the road user in the future.

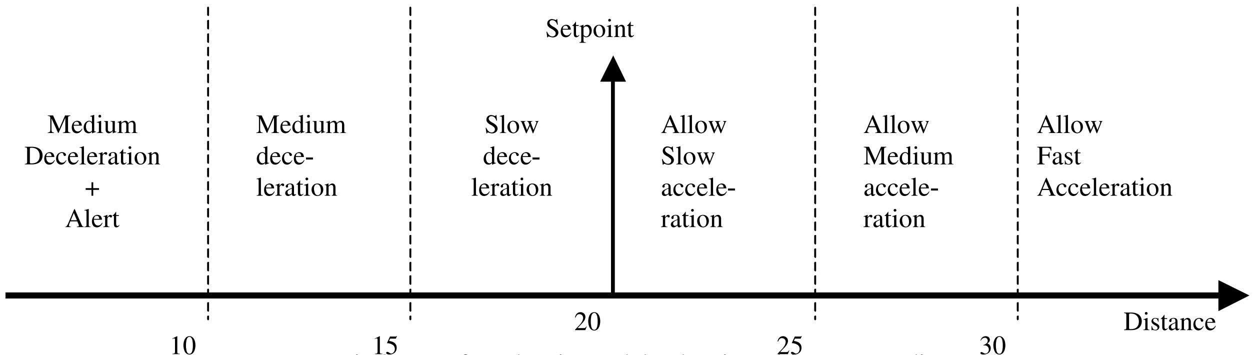

Fig.8 Rate of acceleration and deceleration with respect to distance

References

[1] Michail Petrov, Ivan Ganchev, Krum Kutryanski, A study on the Fuzzy PID Controller, Control System Department, Technical University Sofia

[2] Dr. M. J. Willis (1998, November 17). Proportional-Integral-Derivative Control. [Online]. University of Newcastle.

[3] K. S. Tang, Kim Fung Man, Guanrong Chen, Sam Kwong, An Optimal Fuzzy PID Controller. IEEE Trans. on Ind. Electronics, Vol. 48, August 2001.

[4] Dr. Renner (No Date). Fuzzy Expert System: Fuzzy Logic. [Online] California State University. http://www.ecst.csuchico.edu/~renner/Teaching/ 123/Lectures/negnevitsky/ [2005, 20 June].

[5] Dr. M. J. Willis (1998, November 17). Proportional-Integral-Derivative Control. [Online]. University of Newcastle.http://lorien.ncl.ac.uk/ ming/pid/PID.pdf#search='PID%20pdf'.[2006].

[6] George K. I. Mann, Bao-Gang Hu, Raymong G. Gosine, Analysis of Direct Action Fuzzy PID Cotnroller Structure. IEEE Trans, on Systems, Man, and Cybernetics - Part B: Cybernetics, Vol. 29, No. 3, June 1999.

[7] Bao-Gang Hu, George K. I. Mann, Raymond G. Gosine, A systematic Study of Fuzzy PID Controllers – Function-Based Evaluation Approach. IEEE Trans. on Fuzzy System, Vol. 9, No.5, October 2001.

[8] Control Tutorial for MATLAB. (No Date). PID Tutorial. [Online]. University of Michigan. http://www.engin. umich. edu/group/ctm/PID/PID.html [2005, July 16].

[9] Martin Hellmann (2001, March). Fuzzy Logic Introduction. [Online] http://www.fpk.tu-berlin.de /~anderl /epsilon/fuzzyintro4.pdf [2006, March 20].

[10] Bart Kosko and Satoro Isaka (No Date). Fuzzy Logic. [Online]. Fortune City. http://www.fortunecity.com/ emachines/e11/86/fuzzylog.html [2005, June 20].

Md. Shabiul Islam has submitted his Ph.D. dissertation on the Title "VLSI Implementation of 2-D Discrete Cosine Transform (DCT) for Image Compression" on March 2008 in MMU, 63100 Cybrjaya, Selangor, Malaysia. He has obtained his M. Sc. degree (by research work) in the area of "Micro Controller Based System Design" at the Department of Electrical, Electronic & Systems Engineering, Universiti Kebangsaan Malaysia (UKM), 43600 Bangi, Selangor, Malaysia on 1996. He has received his B.Sc. (Honors) and M. Sc. degrees from the Department of Applied Physics & Electronics, Rajshahi University, Rajshahi, Bangladesh on 1985 and 1986 respectively. Major field of study are Electronics subjects.He has been working as a Lecturer at Faculty of Engineering in Multimedia University (MMU), 63100 Cyberjaya, Selangor, Malaysia since July 1999 to present. He has served as Scientific Officer at the Institute of Electronics and Material Science (IEMS) in Bangladesh Atomic Energy Commission on May 1991 to December 1993. Currently, he is doing his research work on VLSI design related with Fuzzy Logic Algorithm (FLA) for Automation Control application etc. Mr. Islam is a member of Bangladesh Electronics Society (BES), and Bangladesh Computer Society (AM476) in Bangladesh..

Nowshad Amin was born in Chittagong, Bangladesh, on January 5, 1972. He graduated from the Comilla Cadet College, Bangladesh, and later studied at the Universities of Gunma National College of Technology for diploma in Electrical Engineering, Toyohashi University of Technology for BS, Tokyo Institute of Technology for MS and PhD in Electronics, in Japan. His employment experience includes the Motorola Japan Ltd in Tokyo, the University of South Florida in USA, Freescale Semiconductor Japan Ltd in Japan and the National University of Malaysia in Malaysia. His special fields of interest include Microelectronics, Semiconductor Physics and Devices, Optoelectronics.

Mukter Zaman obtained his B.Sc from Khulna University of Engineering and Technology [KUET] Bangladesh, in Computer Science and Engineering, 2003. He is currently working toward the MEngSc by research degree degree at the Faculty of Engineering, Multimedia University, Cyberjaya, Malaysia. His research interests are in the area of embedded control system design, robotics, and image processing.

M.S. Bhuyan obtained his B.Sc. Engg (Hons) from Ahsanullah University of Science and Technology, Dhaka, Bangladesh in Computer Science and Engineering, 2002. He is currently working toward the MEngSc degree at the Faculty of Engineering, Multimedia University, Cyberjaya, Malaysia. His research interests are in the area of VLSI implementation of image processing and video.