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3D PRINTED INTEGRATED FULL-FUNCTION PROSTHETIC HAND-ARM SYSTEM

Mohammed Ismail[1] and B.P. Harish[2]

[1]PG student, Department of Electrical Engineering, University Visvesvaraya College of Engineering, Bangalore University, Bangalore

[2]Professor, Department of Electrical Engineering, University Visvesvaraya College of Engineering, Bangalore University, Bangalore

ABSTRACT

A low cost anthropomorphic robotic full function prosthetic integrated hand-arm system is proposed, using 3D printing technology. Two methods of control are proposed for synthetic hand-arm system: 1. instrumented glove designed to imitate left or right hand to control the prosthetic hand. 2. using electromyography (EMG) signals generated through a sensor mounted on any muscle in the user's good arm. Simple tasks, requiring both the hands, can be achieved, by servomotor controlled finger motions. The rotation of servomotors, acting as actuators, is controlled using a microcontroller. The objective of the proposed work is to build a prototype of a controlled hand-arm system that replicates the full function hand and wrist movements towards the development of low cost solution of prosthesis for people with motoring disabilities.

Keywords: Prosthetic hand-arm system, control schemes, 3D printing, EMG sensor, wearable glove.

1. INTRODUCTION

Many people live their daily lives without one or more limbs. Some people are born with various types and amounts of disabilities or may have lost their limbs in accidents or may be suffering from diseases that result in loss of functionality. Day to day tasks may be very difficult or impossible to perform for disabled people. When a person loses an arm or other extremity, they become very much dependent on others even to perform simple tasks. Hence, there is a need for a technology enabled device that can help them lead an independent life. In this direction, a prosthesis can play an important role in their rehabilitation.

Many different techniques have been proposed to develop a prosthetic hand with varying degrees of success. An anthropomorphic prototype of hand prosthesis with 16 joints, differentially driven by a set of five independent actuators is designed and demonstrated for use with a multi-channel myoelectric interface [1]. The hand prototype provides a set of eight canonical hand postures. While the force and speed capability of the device is experimentally characterized, the design is complex.

The design and fabrication of a fully integrated humanoid robotic hand with embedded sensors and actuators is proposed [2]. The hand with five fingers integrates an embedded shape memory alloy (SMA) actuator and a piezoelectric transducer (PZT) flex sensor. While issues like control of the SMA actuator, better power efficiency, and reduction in response time and actuation current have been addressed, it involves complex designs and fails to mimic human hand.

The design and control issues involved in the development of a dexterous robotic hand with its mechanical structure based on a bio mechatronic approach is proposed, with necessary control systems, for precise positioning of the fingers [3]. The advancements in CNC programs, additive manufacturing, and image editing software offer the possibility of design, printing and remote fitting of prosthetic hand devices at very low cost [4]. In order to achieve maximum replication of functionality of human fingers, Electromyogram (EMG) control is proposed, using mechanical prosthetic replacements [5]. However, the design fails to achieve complete dynamics of a finger.

Using 3D printable technology, two prototypes of prosthesis are fabricated: a hand with 5 fingers controlled by a wearable instrumented glove and a hand-arm controlled by flexing any muscle in the user's arm through an electromyography (EMG) sensor. While microcontroller programs the rotation of servomotor actuators to control finger motions, the complete functionality of wrist movements is not achieved [6].

A prosthetic limb can improve the capability to manage daily activities and to stay independent. In order to facilitate rehabilitation of disabled people, the proposed work introduces a micro-controller based prosthetic hand designed specifically for amputees who have lost their hands in an accident or born with no hands and a prototype is developed using 3D printing technology. The primary focus of the work is to develop a simple but cost effective prosthetic hand designed to imitate motion of human hand as closely as possible.

The paper is organized as follows: Section 2 introduces the block diagram of prosthetic hand-arm system. While Section 3 describes the design and implementation of control schemes to achieve full function prosthetic hand-arm system with a functional prototype, Section 4 presents results and discussion. Section 5 outlines the conclusions of the work.

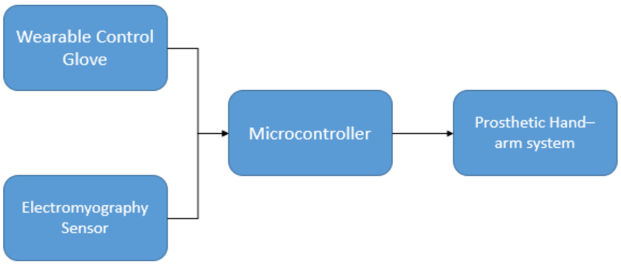


Figure 1: Block diagram of prosthetic hand-arm system.

2. PROSTHETIC HAND ARM: BLOCK DIAGRAM

Two control schemes are proposed for the prosthetic hand-arm system: wearable control glove and electromyography sensor based control. Figure 1 shows the general block diagram of the proposed prosthetic hand-arm system, where control glove and the EMG sensor forms the input device and the prosthetic hand-arm system forms the controlled output device.

a. Wearable control glove

In the proposed work, wearable control glove is one of the two control devices that gives the control signals to the robotic arm. Sensors are embedded within the gloves for gathering information on finger position. The user can control the arm by wearing the glove on the good hand and moving the fingers and wrists of the prosthetic hand-arm system with the corresponding movements of the good hand-arm. Tasks that require two hands are easily performed by the amputee by wearing the glove on the good hand and controlling the prosthetic hand. Sensors are calibrated to detect the finger movements precisely and send control signals to the microcontroller for controlling the prosthesis.

b. Electromyography sensor control

EMG sensor is the second control input to the robotic hand. The muscle contraction of the user's hand is sensed by the sensor and electrical signals are fed to the controller as input. Controller generates the required control signals to the actuators and the robotic hand performs the predefined actions, accordingly.

c. Microcontroller

A microcontroller forms the controlling device of any embedded system. In the proposed work, Atmel ATmega2560 with Arduino Mega board is used for the control. The control signal from control devices – wearable glove and EMG sensor is sent to the microcontroller, which processes the input and sends the output signals to the actuators in the robotic prosthetic arm, which results in the arm performing the required actions.

d. Prosthetic hand

Computer Aided Design (CAD) enabled 3D printing technology is redefining manufacturing in many fields like medicine, due its ability to make tailored products with ease, speed and low cost. The prosthetic hand is designed and the prototype is developed using a 3D printer. The actuators are embedded within the robotic prosthetic arm and the control signals are given from the controller which controls the movements of individual actuators resulting in the movement of the components of the hand-arm system like the fingers and the wrist.

3. PROSTHETIC HAND-ARM SYSTEM: DESIGN AND IMPLEMENTATION

The prosthetic hand-arm system consists of a microcontroller, servomotor setup, the 3D printed prosthetic hand and two schemes of controlling the prosthetic hand – a wearable control glove and EMG sensor.

Control Scheme I: The functional block diagram and the control flow of the prosthetic hand-arm by the wearable control glove is as shown in Figure 2. The user wears a control glove on his/her good hand and the prosthetic hand-arm mimics the user's finger, palm and wrist movements of the good hand-arm.

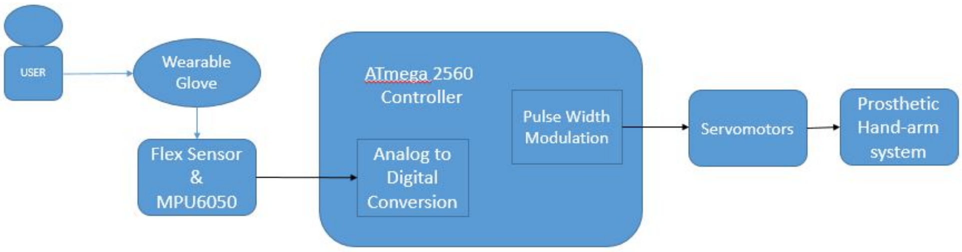


Figure 2: Block diagram of control flow of prosthetic hand-arm system using wearable glove.

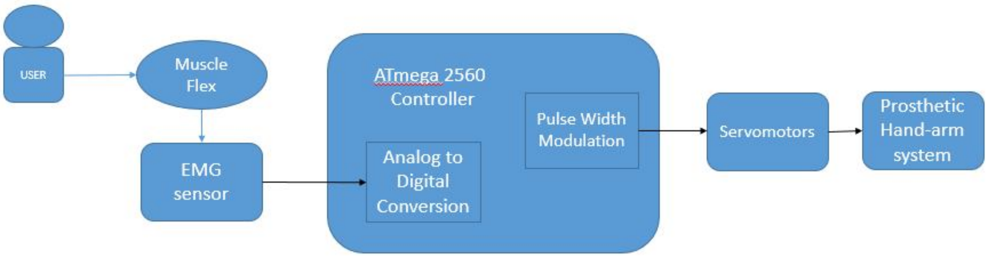


Figure 3: Block diagram of control flow of prosthetic hand-arm system using EMG sensor.

Control Scheme II: Figure 3 shows the functional block diagram and the control of prosthetic hand using EMG sensor. The user is attached with EMG sensor on his/her forearm or biceps and when a muscle is flexed, sensor detects the muscle movement and signal is sent to the Arduino board, which controls the servomotor by sending PWM signals. This in turn controls the movements of fingers, palm and wrist of the prosthetic hand-arm system.

3.4 Prosthetic hand-arm system: Hardware

The hardware setup of the prosthetic hand-arm system consists of Arduino Mega microcontroller board, 3D printed prosthetic hand, and servomotor setup, wearable control glove with flex sensors and MPU6050 gyroscope and EMG sensor.

3.4.1 3D designs

Development of prosthetic hand begins with design of 3D sketches in the computer using Autodesk 123D Computer Aided Design (CAD) tool [7]. The design of prosthetic hand consists of forearm, palm, little finger, ring finger, middle finger, index finger, thumb and the finger base structure. Individual finger has one degree of freedom. Each of these parts is designed and printed separately, and then assembled. The 3D printed prosthetic hand has dimensions of 49 cm in length and 10.5 cm in width [6] and is made of Polylactide (PLA) material. 3D CAD design of the prosthetic hand is shown in Figure 4.

3.4.2 Design of control scheme for prosthetic hand-arm system

The control circuit for prosthetic hand using control glove is shown in Figure 5. The control glove is worn by the user on good hand to read the movements of the fingers, which is detected by varying resistance of individual flex sensors placed on each finger of the glove. When a finger is bent the resistance of that flex sensor varies, leading to change in voltage in the voltage divider circuit. The flex sensor used has a typical resistance of 30 KΩ to 130 KΩ, when the finger is fully bent. This change in voltage, being a continuous signal, is detected by the on-chip ADC of microcontroller on Arduino Mega board to generate a digital signal. The controller analyzes and sends PWM signal to respective servomotor. The wrist movement of the prosthetic hand is achieved by using a 3 axis gyroscope-accelerometer module (MPU6050). MPU6050 module is mounted on the center of the glove to detect the hand rotation. Whenever the user rotates the hand, gyroscope sends signal to the controller, which in turn sends the corresponding PWM signal to the servomotor mounted on the wrist assembly of the prosthetic hand. Initial position of the wrist servomotor will be at 90^o, which is programmed to move at an angle of 90^o from its initial position on both sides, leading to a total of 180º movement of wrist on both sides. To augment the power supply of Arduino board, an external power supply of 5 V, 1 A is given to enable 6 servomotors to run simultaneously.

The control circuit for prosthetic hand-arm system using EMG control is shown in Figure 6. It consists of Arduino Mega board, EMG sensor and servomotors. The EMG sensor which is placed on the user's arm detects muscle activity using biomedical electrode pads.

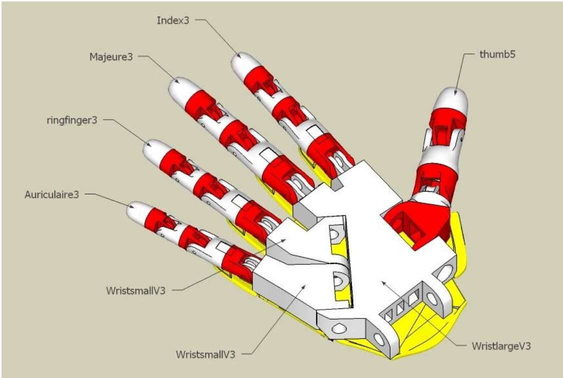


Figure 4: 3D CAD printable design for hand.

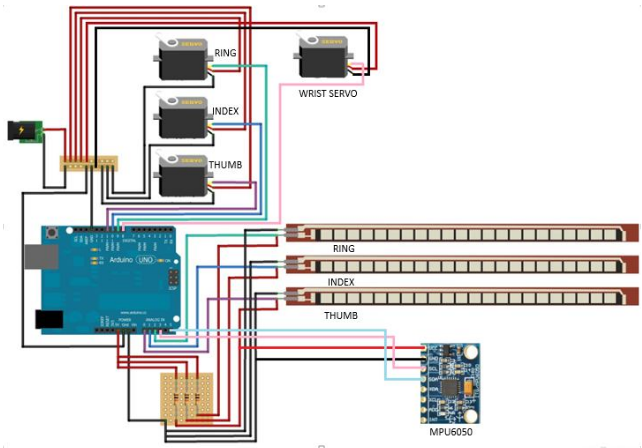


Figure 5: Control circuit for prosthetic hand-arm system using control glove.

The analog signal is converted to digital form by the on chip ADC of microcontroller on Arduino Mega board. The microcontroller generates the corresponding PWM signals to the servomotors mounted on the prosthetic hand. Depending on the input signal, the controller controls all the 5 servomotors for a predefined sequence of movement. This type of control can be used for amputation below elbow where the user can control the prosthetic arm by flexing the bicep muscles of the amputated hand. The task that is performed by the arm is pre-programed into the controller. Simple day to day tasks like holding objects, picking up objects with two hands can be programed into the controller.

3.5 Prosthetic hand-arm system: Software

The control program for prosthetic hand-arm is coded in LabVIEW platform with Linx toolkit. LabVIEW relies on graphical symbols to program the controller actions. Its execution is based on the principle of dataflow, in which functions are executed only after receiving the necessary data. The LabVIEW block diagram for wearable control glove and EMG sensor control schemes are shown in Figure 7 and Figure 8, respectively.

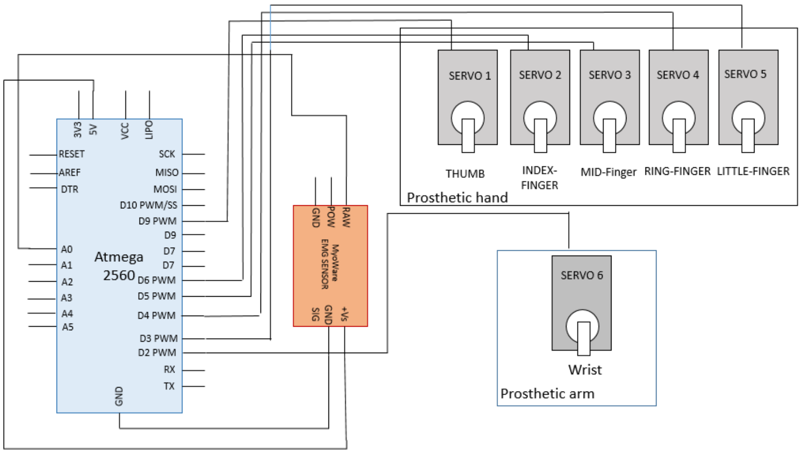


Figure 6: Control circuit for prosthetic hand-arm system using EMG sensor.

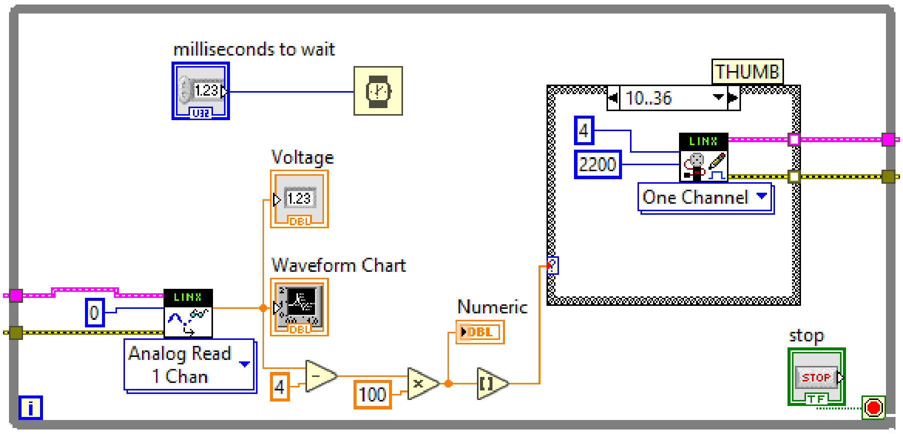


Figure 7: LabVIEW block diagram for wearable control glove scheme.

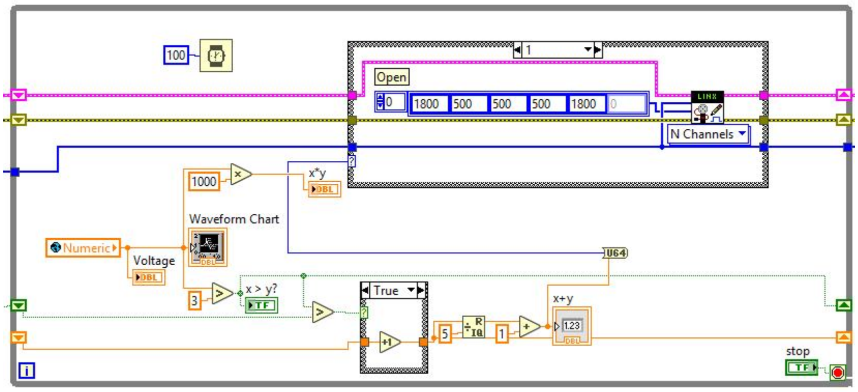


Figure 8: LabVIEW block diagram for EMG sensor control scheme.

4. RESULTS AND DISCUSSION

A prototype of prosthetic hand-arm system is developed using 3D printing technology and two methods of control – wearable control glove and EMG sensor are designed and implemented. Figure 9 shows the control glove for the prosthetic hand system. In the wearable glove method of control, it is observed that movements of each finger can be measured smoothly using flex sensors. Movements of the servomotor is calibrated in the LabVIEW program.

Tests are performed to measure the reliability of the control glove with 50 iterations and the results are tabulated in Table 1. Tests involve closing and opening of the prosthetic hand along with movements of individual fingers. Tests are performed to examine the behavior of prosthetic hand-arm system using EMG sensor control placed, using biomedical electrode pads, on different arm locations. While Figure 10 (a) shows EMG sensor connected to the forearm, Figure 10 (b) shows EMG sensor connected to the biceps. Tests are performed based on closing and opening of hand and finger movements with 50 iterations and results are tabulated in Table 2.

Figure 11 shows strings connecting the fingertips to the servomotors using servomotor pulley. A complete hardware setup of the prosthetic hand-arm system is shown in Figure 12. The base of the setup is designed using acrylic sheets to support the prosthetic hand system. The Arduino Mega controller board is placed next to the prosthetic hand and can be connected to the computer through USB. The power supply to the servomotors is provided by a 5 V, 1 A adaptor which can be connected at the back of the setup using power jack.

The proposed prosthetic hand-arm system provides full functionality of human hand and arm system, including the wrist movement over 180º on both sides, in an enhancement over the work in [6]. Further, both control schemes are demonstrated on the single prosthetic hand-arm system unlike the work in [6] which has used separate prosthetic hand for the two control schemes.

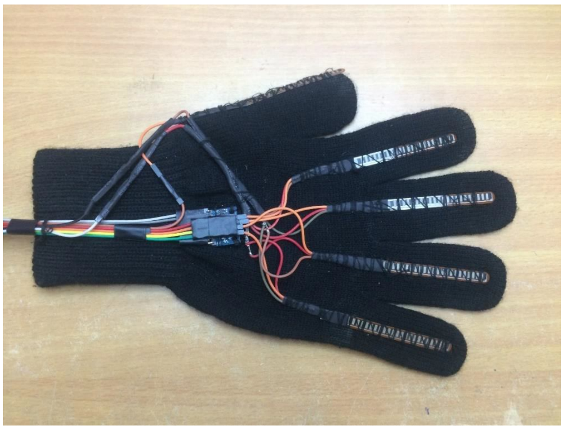


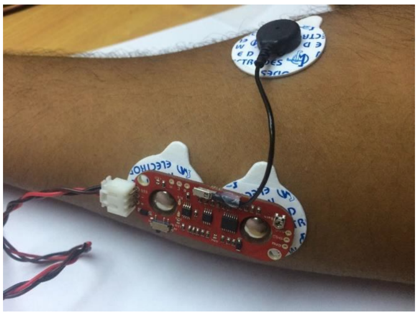
Figure 9: Control glove for prosthetic hand-arm system.

Table 1: Reliability performance of wearable glove control scheme.

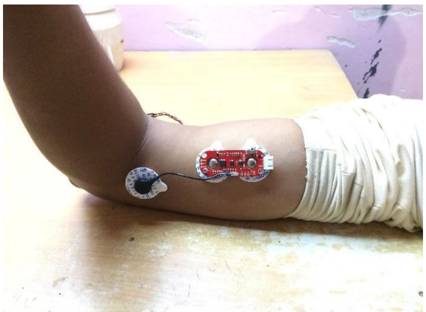
Glove Actions	Correct action	Wrong action	Accuracy (%)
Closing	48	2	96
Opening	46	4	92
Individual fingers	48	2	96

Table 2: Reliability performance of EMG sensor control scheme.

Arm Location	Correct actions	Wrong actions	Accuracy (%)
Forearm	42	8	84
Biceps	45	5	90



(a)



(b)

Figure 10: EMG sensor fixed using biomedical electrode pads on (a) the forearm and (b) the biceps.

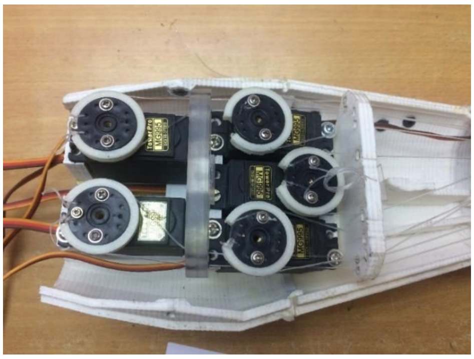


Figure 11: Servomotors base and nylon strings.

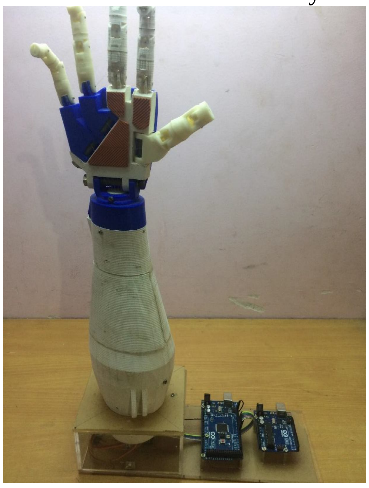


Figure 12: Prosthetic hand-arm system with Arduino board controller.

5. Conclusions

In the proposed work, a low cost robotic prosthetic hand-arm system is designed and a prototype is developed using 3D printing technology. The prosthetic hand-arm system is simple and can be easily custom designed at low cost. Two different control methodologies are simple and low cost and their reliability is demonstrated. The prosthetics is non-invasive in nature, requiring no surgical procedure. The mechanical design of 3D printed prosthetic hand can be easily adapted to different amputation needs and to people belonging to the age group of constant growth, due to the modularity of 3D printing. The technology enabled device helps disabled people in their rehabilitation and help them lead an independent and quality life.

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AUTHORS

Mohammed Ismail received his B.E. in Electronics and Communication Engineering from HKBK College of Engineering in 2015, Bangalore. He is currently pursuing M.Tech. in Control and Instrumentation from University Visvesvaraya College of Engineering, Bangalore University, Bangalore.

B.P. Harish received his B.E. in Electronics and Communication Engineering from University Visvesvaraya College of Engineering, Bangalore University, Bangalore, M.Tech. in Industrial Electronics from Karnataka Regional Engineering College (now called NITK), Surathkal and Ph.D. Degree in Electrical Communication Engineering from Indian Institute of Science, Bangalore, India, with specialization in VLSI Design. Since 1995, he has been with the University Visvesvaraya College of Engineering, Bangalore University, Bangalore, where he is currently a Professor in the Department of Electrical Engineering. He has research publications in various International Journals and Conferences. His current research is focused on process variability studies in nano CMOS, analog design automation, on-chip power electronics, network on chip and instrumentation electronics.

He is conferred with the Seshagiri Kaikani Medal for the Best Ph.D. Thesis in the Department of Electrical Communication Engineering from Indian Institute of Science, Bangalore, in 2007. He is the recipient of the Visiting Research Fellowship at Jawaharlal Nehru Centre for Advanced Scientific Research, Bengaluru. He has received the ISA TechnoInventor Award 2008 for his outstanding research contribution in the area of semiconductors.

He is a Fellow of Institution of Engineers-India (IEI), Senior Member of The Institute of Electrical and Electronics Engineers (IEEE), Member of Institution of Electronics and Telecommunication Engineers (IETE), and Life Member of Indian Society of Technical Education (ISTE).