International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075, Volume-10 Issue-1, November 2020

An Emergency Portable Ventilator for COVID Patients with Acute Breathing Difficulty

Dinesh K. Anvekar, Manjula Vasant Kiresur, Usha B. Siddaiah, Archana R Kulkarni, Narendra Kumar

Abstract: In this paper, a design of a ventilator that meets the demand for emergency ventilators required to help patients with acute breathing difficulty during pandemics such as the current COVID-19 pandemic is presented. The AMBU bag based ventilator can be fabricated at low cost and is easily affordable by hospitals. Based on readily available components, the ventilator will cost about INR6000, and can be easily maintained by even non-technical medical personnel. It works on regular AC supply of 220V and runs on 12V DC supply drawing about 1.5A current. The ventilator is light in weight weighing about 2Kg and is easily portable. The use of individually addressable light emitting diodes and a photo- resistor for positioning of the pushrod is an innovative feature of the ventilator. It meets the requirement of emergency ventilators for use during the waiting period before a full fledged ventilator is available to the patient.

Keywords : Ventilator, Emergency, Respiration, Arduino, Portable, AMBU, individually addressable LED, Photo-resistor.

I. INTRODUCTION

The recent COVID-19 pandemic has created a great demand for ventilators to help patients who have much difficulty in breathing. As the disease is spreading rapidly, there is a need for providing health care institution with additional ventilators [1]. To meet the express demand, any emergency ventilator design has to be easy to fabricate or manufacture. The conventional full fledged ventilators are quite complex in design and need a long time to manufacture [2]. However, for emergency purpose a simple ventilator based on AMBU (Artificial Mechanical Breathing Unit) aka BVM (Bag Valve Mask) [3] can be used. This type of emergency ventilator just sends air, optionally with Oxygen, into the lungs of the patient. Such ventilators are useful when the patient's state is critical and his lungs severely affected by the virus and make it very difficult for the patient to inhale. During the early part this year, several companies, academic institutions, and individuals worldwide made attempts to design emergency ventilators based on the AMBU bag. These designs have a relation to the paper [4] published by MIT researchers in 2010 and the ventilator design proposed by the MIT E-Vent Project Team.

An excellent review of open source ventilators suitable for COVID-19 patients is given by Pearce in [9]. With 159 references cited in this paper, perhaps it is one of the best papers to get an overview of the open source ventilators. The interested reader is encouraged to read this paper to get a good background for the emergency ventilator presented here.

In this paper, we describe a simple microcontroller controlled ventilator design that is affordable, portable, light weight and that can be fabricated easily with readily available parts, and kept ready for emergency services in hospitals.

II. HARDWARE DESIGN

A. Mechanical Hardware

The schematic diagram of the emergency ventilator is shown in Fig. 1, brings out the different functional blocks and their relationship.

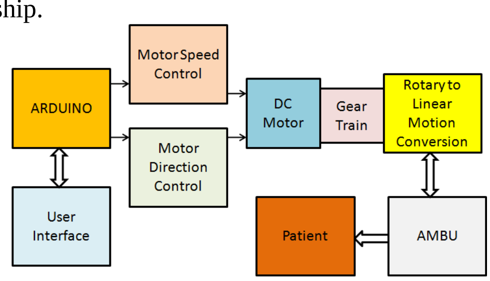

Fig. 1 A schematic diagram of the emergency ventilator

The ventilator is based on a standard medical grade AMBU bag that has the necessary valves for sucking in air and pushing it out of the output port. It has the provision for adding oxygen if required. The patient is supplied the air by means of a mouth piece which is connected to the AMBU by two flexible tubes. When the AMBU bag is pressed, its volume is reduced because of deformation, and the pressure of the air inside is increased making it to be pushed out of the output port. In our design, the AMBU is pressed by the hemispherical end of a pushrod which is connected to a rack that is constrained to move linearly along a groove. The rack is driven by pinion gear which is connected through a gear train to the shaft of a 12V DC motor. The 12V DC motor is controlled by an LM298 IC based DC motor controller module which has two TTL compatible inputs IN1 and IN2 for direction control, and one enable input ENA for speed control by PWM technique. The direction control logic of the motor controller is shown in Table 1.

Revised Manuscript Received on November 01, 2020.

* Correspondence Author

Dinesh K. Anvekar*, Professor,ECE Dept., RNS Institute of Technology, Bengaluru, India. Email: dinesh.anvekar@gmail.com

Manjula Vasant Kiresur, Assoc. Professor,ECE Dept., RNS Institute of Technology, Bengaluru, India. Email: manjulakiresur@gmail.com

Usha B. Siddaiah, Asst. Professor,ECE Dept., RNS Institute of Technology, Bengaluru, India. Email: bsusha@gmail.com

Archana R. Kulkarni, Asst. Professor,ECE Dept., RNS Institute of Technology, Bengaluru, India. Email: archana.anv@gmail.com

Narendra Kumar, Asst. Professor,ECE Dept., RNS Institute of Technology, Bengaluru, India. Email: nkrnsit1@gmail.com

Table- I: LM298 Motor Direction Control Logic

IN1	IN2	Direction
Low(0)	Low(0)	Motor OFF
High(1)	Low(0)	Forward
Low(0)	High(1)	Backward
High(1)	High(1)	Motor OFF

The ENA input when ‘Low’ cuts off power to the motor and when ‘High’ enables the motor shaft to spin at the rated speed in clockwise or anticlockwise direction if one of the inputs IN1 and IN2 is exclusively ‘High’. (forward if IN1=1, and backward if IN2=1). The motor is “OFF” if both IN1 and IN2 are either ‘Low’ or ‘High’.

A. Pushrod Stroke Control

A picture of the pushrod with the AMBU bag is shown in Fig. 2. The tip of the pushrod has a hemispherical pusher so that the contact with the AMBU is gradual and smooth, and the bag is not damaged by its getting repeatedly pressed as required in this application. The pushrod is connected rigidly to the rack which is driven left or right by the pinion. When the rack is driven to the left the pushrod also moves to the left pushing the AMBU with the pusher. The amount of air pushed out of the AMBU is proportional to the length of the stroke of the pushrod. Therefore, the tidal air volume can be controlled by adjusting the stroke length. The sensing of the position of the pushrod is achieved by us in a unique way by using Individually Addressable LED (IALED) strip WS2812B. To get 8 positions for the pushrod, a strip of 8 IALEDs are assembled on a base such that the top surface is even and the light from the IALEDs can pass out through 8 holes on the base. An LDR is mounted on the lower surface of the pushrod in a

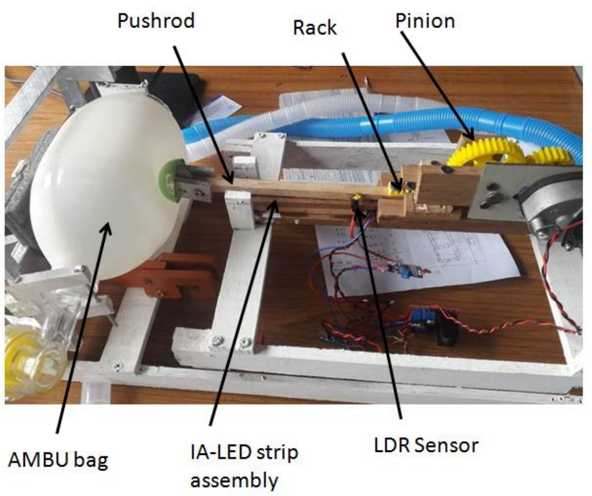

Fig. 2 Different parts of the emergency ventilator

countersunk hole. When the pushrod moves over the IALED base, the LDR module produces a ‘High’ sense signal when it is directly above the IALED which is lit. By turning 1 of the 8 IALEDs and by monitoring the LDR signal we can know whether the pushrod has moved to the corresponding position. The IALED 0 which is on the extreme right position as shown in Fig. 2 is used to mark the stroke starting position.

As generally recommended by medical personnel, the AMBU should be pressed only to about 2/3 of its full volume (1600ml) while ventilating patients [10-13]. Considering this, only the IALEDs 3-6 are used to control the stroke of the pushrod. The choice of the volume of ventilation and the rate of ventilation is done by using two press buttons interfaced to the Arduino Nano microcontroller. The indication of the chosen level of ventilation and the rate is done by using 11 IALEDs which are cascaded with the IALEDS used for pushrod position sensing as shown in Fig. 3. The final position of the pushrod after its traversal against the AMBU bag determines the volume of the air pumped out. Table II indicates the amount of air volume pumped out of the AMBU bag and is settable at 4 levels (1-4). In the actual design with 8 IALEDs 7 different levels are possible as the first IALED is the reference for the starting position. But, as blowing too much air can be injurious to the lungs as per medical professionals, the maximum tidal volume is limited to 1088ml at level 4. The volume levels are indicated by IALED 8-11. The volume of air to be pumped to the patient is monitored and controlled by the operator manually by selecting the appropriate volume level by using the volume button. If the patient requires more/less air as monitored by the operator, the ventilator is stopped by pressing a start/stop button and the volume button is used to change the tidal volume manually. Pressing the start/stop button starts the ventilator with the newly set

Table- II: Tidal volume

Pushrod Position (Air Volume Level)	Tidal Volume, ml
1	476
2	665
3	864
4	1088

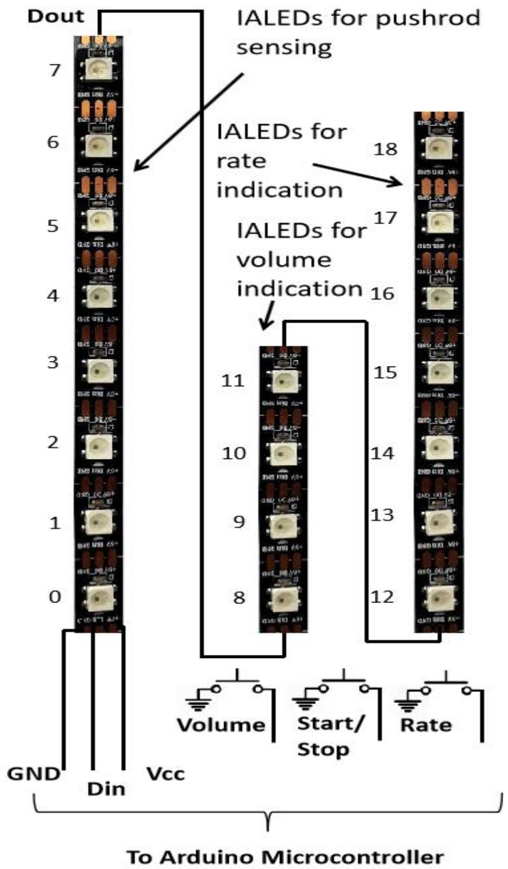

Fig. 3 IALEDs for position sensing and user interface

levels for tidal volume and rate. The volume of air pumped is correspondingly regulated (increased/ decreased) by adjusting the stroke length. The plot of pushrod position level (volume level) vs tidal volume of air (ml) is shown in Fig. 4. It can be seen that the air push out almost linearly increases with the different positions of the pushrod. For any volume level, the rate at which the air is pumped can be controlled by using the rate button. Table III and Fig. 5 show the rate (bpm) at which air is pumped for different rate levels. The current rate value is displayed on the seven IALEDs 12-18 (Fig. 3). Depending on the rate value selected by an operator by using the rate switch as per the patient requirement, the delay between successive pressing of the AMBU bag by the pushrod is adjusted. It can be seen in Table IV and Fig. 6 that the delay T_i between pumps (pumping rate) is more with rate level 1 and minimum with rate level 7.

Fig. 4 Plot of tidal volume

The Table III lists the different rate levels (i.e frequency at which the pumping action takes place) and the corresponding bpm values and a plot of the same is shown in Fig.5. It can be seen that the bpm nonlinearly related with rate level.

Table- III: Breaths per minute (bpm)

Rate Level	Ventilation rate, bpm
1	8
2	9
3	10
4	10.5
5	11
6	11.5
7	12

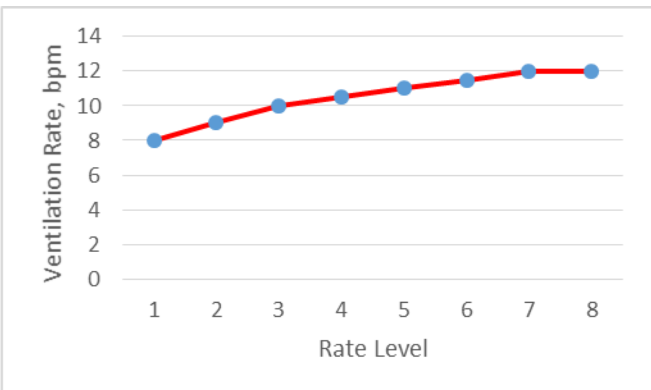

Fig. 5 Relation of bpm and rate levels

Table- IV: Time delay between strokes

	Delay Period T_i for Ventilation Rate						
Volume Level	1	2	3	4	5	6	7
1	7.7	5.2	4.4	3.7	3.4	3.2	2.9
2	8.0	5.5	4.7	4.0	3.7	3.5	3.2
3	8.4	5.9	5.1	4.4	4.1	3.9	3.6
4	8.7	6.2	5.4	4.7	4.4	4.2	3.9

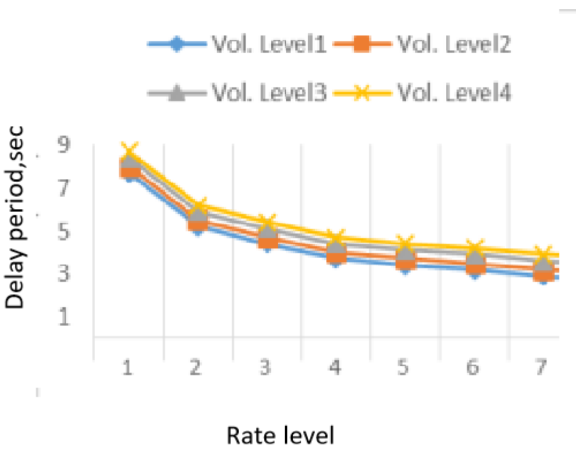

Fig. 6 Relation of delay period T_i and rate levels

III. AIR VOLUME CONSIDERATION

A. AMBU volume and tidal volume

Consideration of volumes of air with reference to use of AMBU bags have been done by several researchers [5-7]. Generally, the volume of AMBU bags ranges from 1400 ml to 1800ml, and the corresponding tidal volumes for adult patients are from 600ml to 830ml, respectively. Petsiuk A. et.al [8] have presented a detailed design of an AMBU bag based ventilator. They have used three different flat and rectangular pusher ends with AMBU contact areas of 14, 42, and 74 cm^2, and found the different tidal volumes for different pressing depths of the AMBU. In our design, as seen in Fig. 2, the pusher end is a hemisphere with a diameter of 3.5cm and a surface area of 19.23 cm^2 . The tidal volumes for our ventilator, as shown plotted in Fig. 7, follow a near linear variation with respect to the pressing depth .

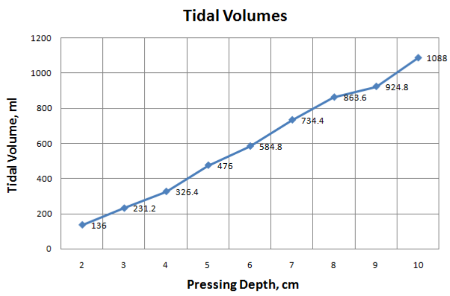

Fig. 7 Tidal volumes of the ventilator

IV. SOFTWARE

The software required for controlling the pushrod operation as per the chosen volume and rate values is developed in C-like language of the Arduino IDE (Integrated Development Environment).

A high level flowchart for the software is shown in Fig. 8. Upon power-on, in Step 1, the program selects the input and output ports, initializes the IALED array, sets default values for the tidal volume and breathing rate, and controls the motors to bring the pushrod to its idle position which is the farthest away from the AMBU bag. In Step 2, the program then waits for the start/stop button (shown in Fig. 3) to be pressed.

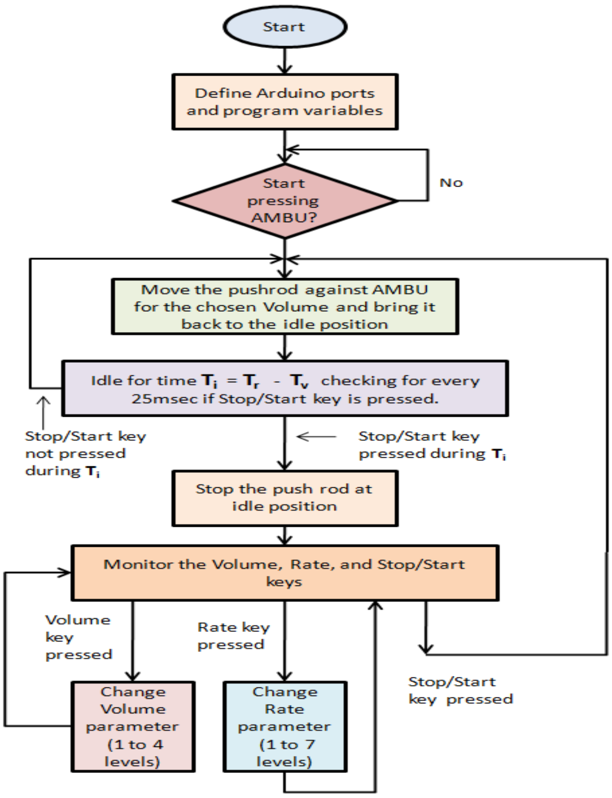

Fig. 8 Flowchart for the software of the ventilator

When started, the program goes to Step 3 wherein it performs one stroke of the pushrod against the AMBU bag, and goes into and idling period during which it checks for every 25msec whether any of the keys is pressed. If either the rate or the volume button is pressed, it appropriately changes the rate and volume variable, respectively. When the start/stop key is pressed, the program comes out of the idling mode and goes back to Step 2 and resumes the pushrod control function. However, if none of the keys is pressed during the idle period, the full delay period T_i is timed out, and the cycle starts again going back to Step 2.

V. DISCUSSION

The design of a simple emergency ventilator that can be readily manufactured to meet the increasing need for COVID infected patients with acute breathing difficulty has been presented in this paper. A prototype of the emergency ventilator is shown in Fig. 9. The stroke cycle time and other timings are found to as required by design. The measured stroke times for the 4 volume levels are shown in Table V.

Fig. 9 A prototype of the ventilator

Table- V: Measured strokes times

Volume Level	Stroke time, sec
1	1.3
2	1.6
3	2.0
4	2.3

While the emergency ventilator is not a substitute for conventional regular ventilators used by medical professional for patients needing breathing support, it is definitely useful in providing immediate relief for COVID and other types of patients until a regular ventilator is available. Several improvements can be made to this basic version of the ventilator. For example, the blood Oxygen level of the patient can be displayed by using the same principle used by commercially available Oximeters. Also, the pulse rate can be displayed. These two values can help the operator to change the volume and rate levels. Alternatively, the system can automatically change the two manually settable levels as per a chart recommended by medical experts. The prototype uses an inexpensive automotive windshield wiper DC motor and readily available rack and pinion parts, and as such they produce noise which can be very undesirable for patients as well as care takers. The noise can be greatly reduced by enclosing the motor, rack and pinion in a rubble shroud with telescopic bellows for the push rod. Another approach is to use a stepper motor instead of a DC motor, but this approach increases the cost. In this version of the ventilator, for the available stroke length (about 10cm) and with inter-IALED distance of 2cm in a WS2812B strip, only 4 levels for air volume as possible. By cutting the IALEDs out of the strip, placing them perpendicular to the pushrod movement direction, and reconnecting them, 8 levels for volume can be achieved. Another significant improvement that can be made is monitoring the air pressures at the inhalation and exhalation point near the patient, and control the rate and volume of air pumping.

VI. CONCLUSION

We have presented sufficient details of an emergency ventilator in this paper to enable technical persons to easily fabricate and put it to use for emergency purpose. It should be noted that ventilation of patients is a task well executed by medical experts, and the emergency ventilators of the type described here are not substitutes for regular ventilators. However, in situations wherein regular ventilators are not immediately available, or during transportation of patients to hospitals in ambulances, the emergency ventilators can act as stop-gap equipment to give some relief to the patients before expert medical care is given.

ACKNOWLEDGMENT

The authors would like to acknowledge the encouragement and support given by Dr. Vipula Singh, HOD of ECE, RNSIT, Dr. Venkatesha M.K., Principal, RNSIT, and Dr. H.N.Shivashankar, Ex-Director, RNSIT. Also, our acknowledgment is due to Mr. Shivayogaiah S. O., Mr. Anand M., and Mr. Vasanthkumar, Laboratory Assistants in the ECE Department for help during the making of the ventilator.

REFERENCES

1. Tian S, Hu W, Niu L, Liu H, Xu H, Xiao SY (2020) Pulmonary pathol- ogy of early-phase 2019 novel coronavirus (COVID-19) pneumo- nia in two patients with lung cancer. J Thorac Oncol 15:700–704. https://doi.org/10.1016/j.jtho.2020.02.010
2. Folmer K (2020) "We'll take them all": demand for ventilators spikes as coronavirus looms [online]. ABC News. https://abcnews.go. com/Health/demand-ventilators-spikes-coronavirus-looms/story?id=69597233. Accessed 10 Apr 2020
3. Hess D, Kacmarek RM (1996) Essentials of mechanical ventilation. McGraw-Hill, New York
4. Al Husseini AM, Lee HJ, Negrete J et al (2010) Design and prototyping of a low- cost portable mechanical ventilator. J Med Devices 4(2):027514
5. Hess D, Spahr C. (1990) "An evaluation of volumes delivered by selected adult disposable resuscitators: the effects of hand size, number of hands used, and use of disposable medical gloves." Respiratory Care. 35(8):800-5.
6. Kroll M, Das J and Siegler J. (2019) "Can Altering Grip Technique and Bag Size Optimize Volume Delivered with Bag-Valve-Mask by Emergency Medical Service Providers?" Prehospital Emergency Care. 23:2, 210-214
7. Khoury A, Sall FS, De Luca A, et al. (2016) "Evaluation of Bag-Valve-Mask Ventilation in Manikin Studies: What Are the Current Limitations?". Biomed Res Int. 2016: 4521767
8. Petsiuk A. et.al.," Partially RepRapable automated open source bag valve mask-based ventilator",HardwareX 8 (2020) e00131, pp. 1-26.
9. Pearce JM., "A review of open source ventilators for COVID-19 and future pandemics," [version 2; peer review: 3 approved]. F1000 Research 2020, 9:218 (https://doi.org/10.12688/f1000research.22942.2)
10. Floyd Miracle "How to Master BVM Ventilation" https://www.aclsmedicaltraining.com/blog/master-bvm-ventilation/ 5, March, 2016.
11. "Beginner Facemask Ventilation Techniques | Emsworld.Com". EMSWorld.com. N.p., 2016. Web. 17 Mar. 2016.
12. Gerstein NS, et al. "Efficacy Of Facemask Ventilation Techniques In Novice Providers. – Pubmed – NCBI". Ncbi.nlm.nih.gov. N.p., 2016. Web. 17 Mar. 2016.
13. "Part 4: Adult Basic Life Support". Circulation 112.24_suppl (2005): IV-19-IV-34. Web. 17 Mar. 2016

AUTHORS' PROFILE

Dr. Dinesh K. Anvekar Dr. Dinesh Anvekar is a senior Professor in ECE Dept of RNS Institute of Technology, Bengaluru. He worked as Principal of Alpha College of Engineering. He also worked as HOD of Dept. of CSE at NMIT, Bangalore and Director Entrepreneurship and Professor of Computer Science at CMRIT. He obtained his Bachelor degree from University of Visvesvaraya college of Engineering. He received his Master's and PhD degrees from Indian Institute of Science. He received best Ph. D Thesis Award from Indian Institute of Science. He has completed two Nokia sponsored projects in Indian Institute of Science during 1997-1998. He has 15 US patents issued for work done in IBM Solutions Research Center during 1998-99, Bell Labs during 1993-94, and Lotus Interworks during 2000-04, and for Nokia Research Center, Finland. He has authored a book and over 55 technical papers. He is a Fellow of IETE and Senior Member of IEEE. He has supervised over 40 undergraduate and graduate engineering projects and research students in the Indian Institute of Science.

Dr. Manjula Vasant Kiresur, obtained her B.E Degree in Electronics and Communication Engineering in 1998, MTech in VLSI & Digital Communication from BVBCET now KLE university under VTU in 2000 and PhD Degree in 2019 in area of Software Defined Radio domain . She is working as Associate Professor in Dept. of Electronics and Communication Engineering in RNS Institute of Technology, Bengaluru since 2002. She has more than 20 years of teaching experience. She has been a reviewer for international conferences and journals. She guided several UG and PG projects. She has published more than 15 technical papers in various Journals, International and National Conferences. Her areas of interest include Wireless Communications, Embedded systems and Digital Image Processing.

Dr. Usha B Siddaiah obtained her B.E and M.Tech from from Sri Jaya Chamarajendra College of Engineering, Mysuru and Ph.D from VTU. Currently working as Assistant Professor in Dept. of Electronics and Communication Engineering in RNS Institute of Technology, Bengaluru. She has more than 20 years of teaching experience. She has guided several innovative projects for U.G and P.G students and has authored one books and has published more than 15 technical papers in various National and International Conferences. Her area of interest includes Biomedical signal processing, digital systems design and Embedded systems..

Dr. Archana R. Kulkarni obtained her B.E Degree from KUD in 1998, MTech in VLSI Design and Embedded Systems from VTU in 2006 and PhD Degree from VTU in 2018. She is working as Assistant Professor in Dept. of Electronics and Communication Engineering in RNS Institute of Technology, Bengaluru since 2005. She has more than 21 years of teaching experience. Has played a key role in setting up laboratories and guided several UG and PG projects. She has authored one book and has published more than 20 technical papers in various Journals, International and National Conferences. Her area of interest includes Embedded systems and Wireless Sensor Networks.

Mr..Narendra Kumar obtained his B.E from RV College of Engineering,Bangalore, M.Tech from BMS College of Engineering, Bengaluru and pursuing Ph.D in Biomedical signal processing from VTU. Currently he is working as Assistant Professor in Dept. of Electronics and Communication Engineering in RNS Institute of Technology, Bengaluru. He has more than 18 years of teaching experience. He has guided several innovative projects for U.G and P.G students. He has authored eight books and has published more than 15 technical papers in various National and International Conferences. He has also delivered many special lectures in various Engineering Colleges. Mentor and advisor for few startups.His area of interest includes Biomedical signal processing, Communication engineering and Embedded systems.