

# ELECTRICAL ENGINEERING RELOADED

for

Life, Data and Sustainability

The Journey continues in a pandemic year .....

Abubakr Muhammad & the EE Faculty  
January, 2021

# University Education in the 21<sup>st</sup> century

What would it mean to be human in the age of artificial intelligence, synthetic biology and the Anthropocene?

Human experience in 21<sup>st</sup> Century <sup>?</sup> =  
Life + Data + Sustainability



**Communication Systems**

**Computer Networks**

**DSP and Image Processing**

**Electronics & Embedded Systems**

**Control Systems & Robotics**

**Energy and Power Systems**

**Devices and Materials**

**Optics & Electromagnetics**

**REIMAGINING EE**





# TENURED

Three tenure applications under review.  
> 50% will be tenured by end of 2021.

2 Professors  
11 Associate Professors  
9 Assistant Professors



Dr Hassan  
Khan



Dr Nauman  
Butt







(Data) AI Hardware and  
Theoretical Foundations

(Life) Biomedical Devices and  
Point-of-Care Healthcare

(Sustainability) Systems View of  
the Water-Energy-Food Nexus



# Portable lab kits for online-learning



EE 324

MICROCONTROLLERS  
& INTERFACING

Dr. Jahangir Ikram

Each kit contains micro controllers, LED matrix, programmable chips, digital-to-analog converters, an oscilloscope, power distribution core, a complete tool set, a multimeter, speed controllers and motors.

Dr Jahangir Ikram's team developed & shipped **50+ lab kits** indigenously for EE-324.

Heroic effort by ALL EE faculty throughout 2020.

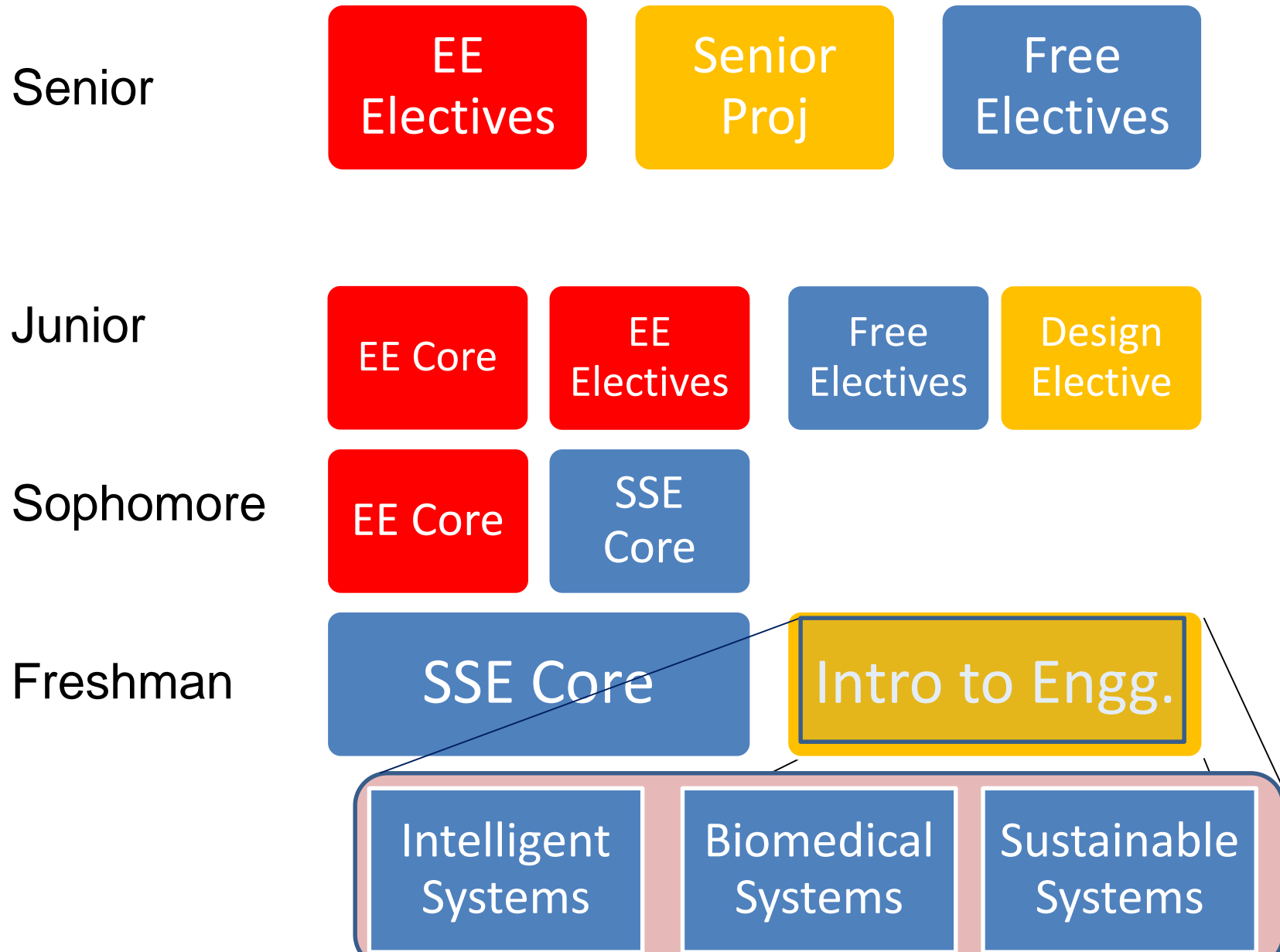
Minimal damage to teaching & research programs.



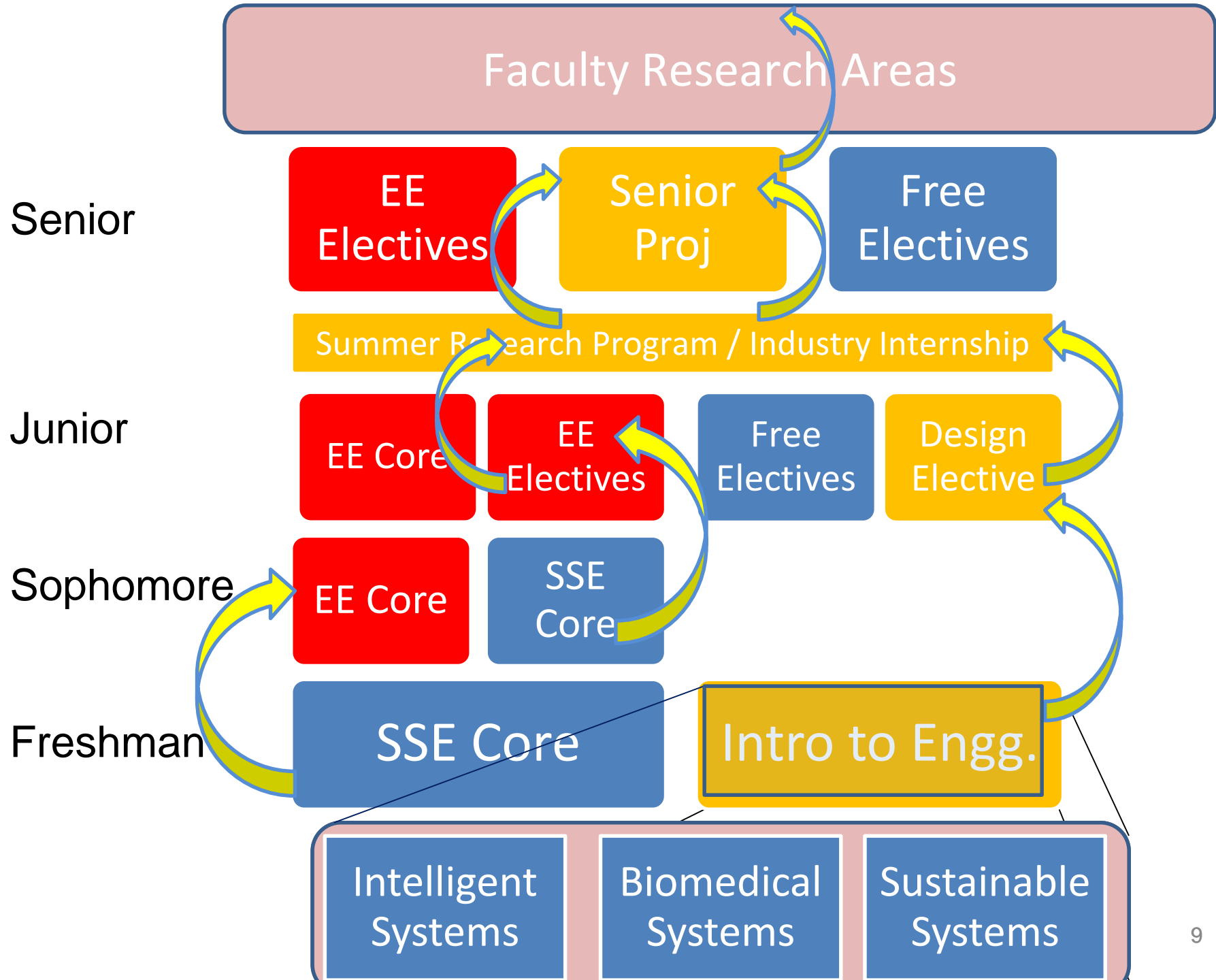
# Portable lab kits for online-learning



# EE100. The Revolution Begins!







# EE-100 Fall 2020: Instructors & TAs



**Dr. Momin Uppal**



**Dr. Abubakr Muhammad**



**Dr. Muhammad Tahir**



**Dr. Awais Bin Altaf**



**Dr. Hassan Jaleel**



**Dr. Nauman Butt**



**Dr. Hassan Mohy Ud Din**



**Eesha Atif**  
**EE Senior**



**Hamza Ather**  
**2020 graduate**



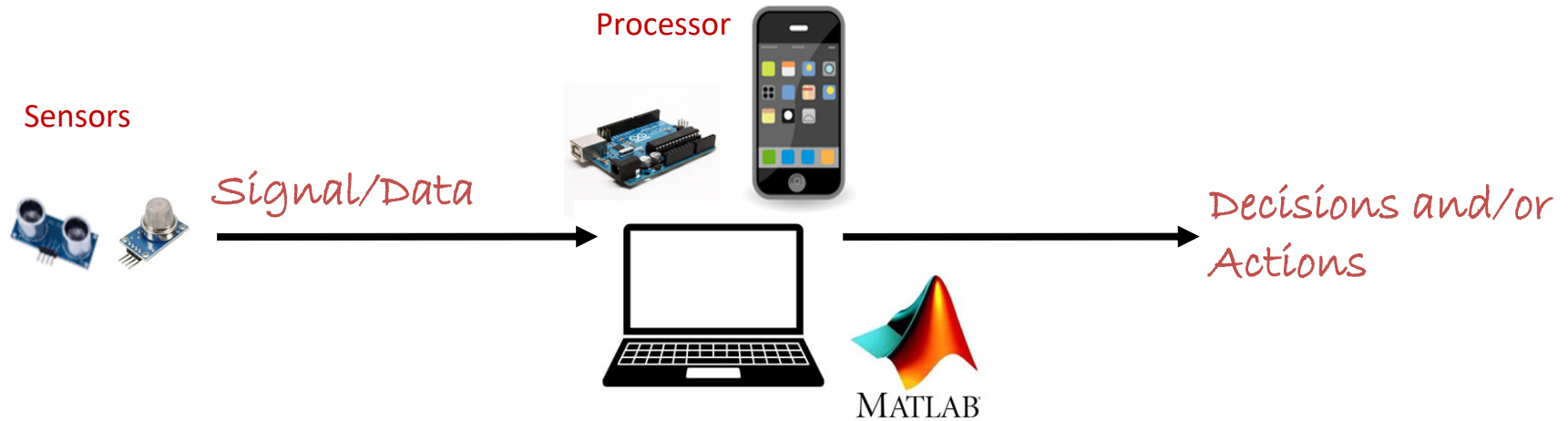
**Nouman Arshad**  
**Senior Lab Engineer**



**Syed Hasan Amin Mahmood**  
**2020 graduate**



# Content Overview



Recording

### Applications: Filtering

Noisy (Time-Domain) Signal

Low-Pass Filter

Amplitude  $|X(f)|$

Frequency (kHz)

Participants (61)

Find a participant

- Muhammad Abubakr (Me)
- Momin Uppal (Host)
- 24100001\_Hooraina Hassan Sid...
- 24100002 Abdur Rehman Khalid
- 24100006 - Wjeeh Azeem
- 24100012\_Muhammad Saad

Chat

From 4\_Daniel Batla to Everyone:  
it doesnt allow values over a certain limit ?

From 24100049 - Adil Hyder to Everyone:  
it'll only allows lower frequencies to pass

From 4\_Daniel Batla to Everyone:  
and amplitude

From 24100055 - M. Haris Saad to Everyone:  
Frequencies lower than the lower pass cannot pass through  
They won't be heard

To: Everyone

Type message here...

# Student participation



One student group beat a classification accuracy target set by faculty and TAs in their final course project.



# Outcomes & Way Forward

- Lab Tasks: Trickle-down of departmental research into freshman teaching
  - Radio Frequency sensing
  - Biomedical signal acquisition
  - Lab-on-a-chip and cell counting
  - Acoustic event detection and localization
  - Intelligent decision-making in agriculture and irrigation
- Spring 2021: Two flavors being offered for EE-100 (1-CH)
  1. Intelligent systems (Full flavor)
  2. Sustainable systems (Full flavor)
  - Biomedical system (invited lectures)

# Transdisciplinary Pedagogical Partnerships

EE 5212/ENGG 342

## FUNDAMENTALS OF BIO NANOTECHNOLOGY

BLENDING BIOLOGY WITH ENGINEERING

IN THIS COURSE YOU WILL LEARN

- NANOTECHNOLOGY APPLICATIONS IN BIOSENSING
- BASIC CONCEPTS OF NANOTECHNOLOGY
- NANO TECHNOLOGY EQUIPMENT + TECHNIQUE
- BIOLOGICAL SENSORS
- NANO FABRICATION

TEXTBOOK NOT REQUIRED

OPEN FOR PUBLIC AUDIT

AN ELECTIVE COURSE BY  
**PROF. DR. SAMIR IQBAL**

Credit Hours | Starting Jan 18, Mon/Wed: 8AM - 9:15 AM

 Syed Bahar Ali  
School of Science and Engineering

Biology or Material Science background is NOT required



EE 5612 / SCI 302 (WIT Center)

SOCIO-ECOLOGICAL SYSTEMS &  
SUSTAINABILITY

Dr. Talha Manzoor

EE 557 (Energy Institute)

ELECTRICITY MARKETS

Dr. Hassan A. Khan, Dr. Fiaz Chaudhry

EE 212 (Continuing Education Studies)

MATHEMATICAL FOUNDATIONS FOR  
MACHINE LEARNING & DATA SCIENCE

Dr. Zubair Khalid

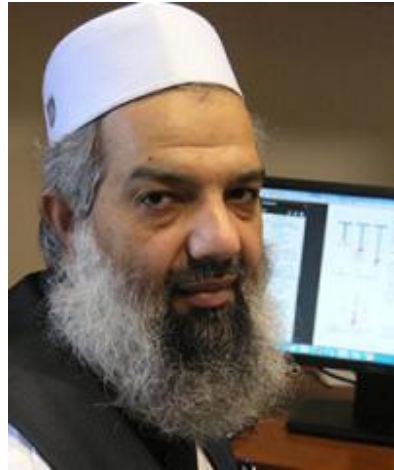
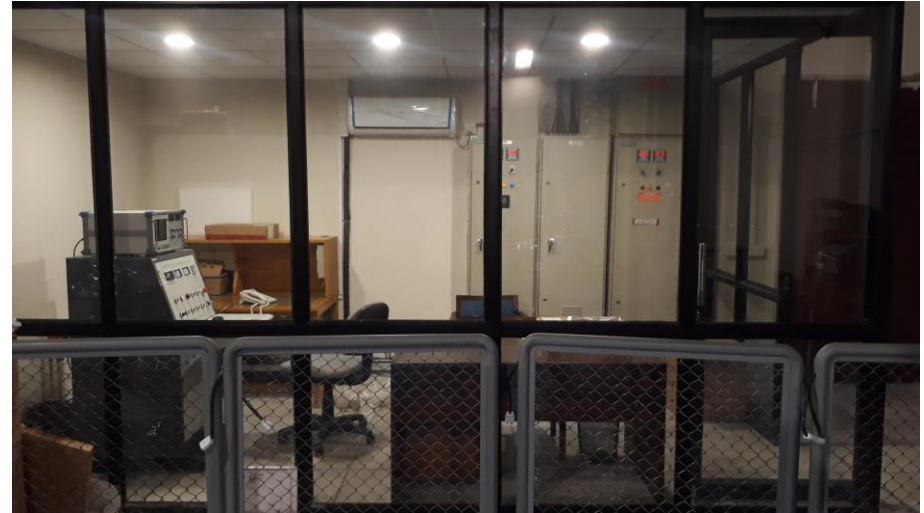
EE 5213 / CS 623 (CS Dept .)

HARDWARE ARCHITECTURES FOR AI

Dr. Rehan Hameed



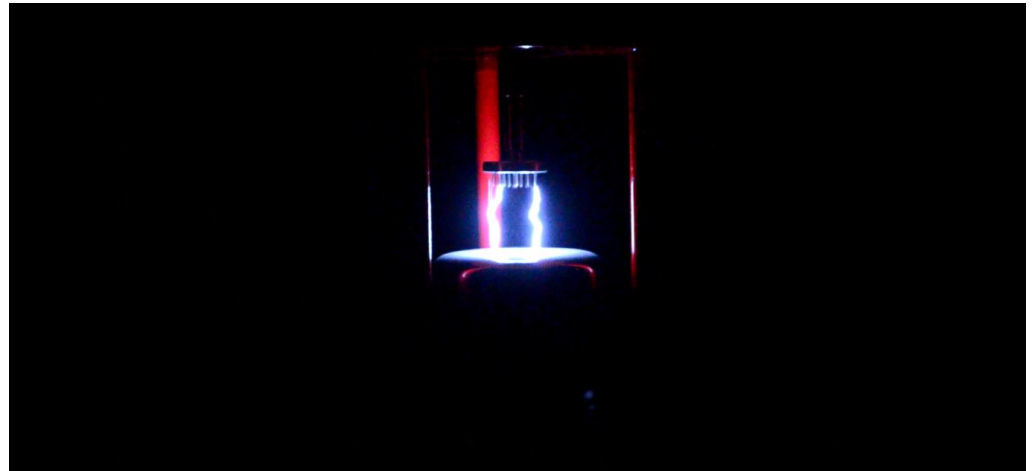
# High Voltage Laboratory Commissioned!



Conceived and designed by:  
Dr Iqbal Qureshi and Dr Tariq Jadoon



# High Voltage Laboratory Commissioned!



EE 553

HIGH VOLTAGE ENGINEERING

Dr. Iqbal Qureshi

# Industry Partnerships



Prof. Nauman Zaffar



Dr Wasif Khan



Dr Awais bin Altaf



Dr Adeel Pasha

**EE External Relations Committee**



# Industry Partnerships



Prof. Nauman Zaffar  
EE External Relations Committee



Dr Wasif Khan



Dr Awais bin Altaf



Dr Adeel Pasha

- Negotiation with multiple organizations for tailored fully funded MS Programs
  - Digital IC Design
  - Intelligent systems
  - Space applications
- One organization has agreed to fund 10x MS students.
- Similar negotiations underway with two others.

# Industry Partnerships



Prof. Nauman Zaffar  
EE External Relations Committee



Dr Wasif Khan



Dr Awais bin Altaf



Dr Adeel Pasha

- **An Electronics Hardware Accelerator / Technology Fund**
  - Enabling productization and commercialization of basic research prototypes
  - Provide an income source to propel basic research
- ABL has agreed to support the initiative with PKR. 3M for first year.
- Many others have shown interest.

# Industry Partnerships



## Make in Pakistan Hackathon 2021



Exports Rising

- 1- Entrepreneurial Ecosystem is growing in Pakistan
- 2- But Manufacturing industry is losing its competitive edge
- 3- Manufacturing Industry's Contribution to GDP reduced from 17.5% to 12.5% from 2012 to 2018
- 4- Pakistani Companies are losing Global Market share.
- 5- To solve the challenges of local industry and to spur innovation, a 16 weeks long project 'Make in Pakistan Hackathon: Connecting the Industry to Incubation Centers' is designed.

### Hackathon preparation: (spread over 3 months)

- 1- LUMS faculty will identify challenges of local industry.
- 2- Challenges will be uploaded on a web portal.
- 3- Focused Seminars by Challenge owners for the hackathon.
- 4- Solutions provider will submit proposals against uploaded challenges.
- 5- Solutions providers will have access to Makers Lab for prototypes for 2.5 months.
- 6- Short-listed teams will be connected with industry to better prepare for Hackathon.
- 7- A series of panel sessions about Pakistan's different industries.
- 8- One day crash course on entrepreneurship.
- 9- The winners after the demo of solutions will be offered an opportunity to get incubated at different centers of entrepreneurship.

\*Dates of different activities will be announced soon.

Connecting centers of entrepreneurship with industries across:

Lahore



Sialkot

Gujranwala



16 weeks long project

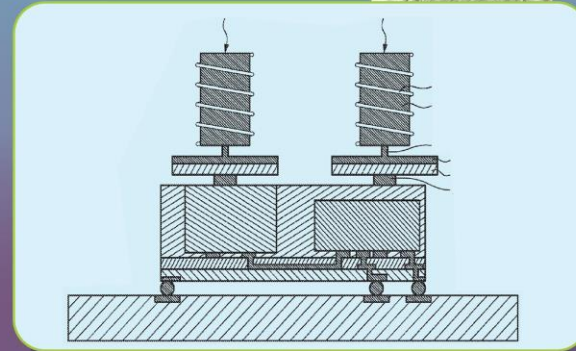
## 2- Day

"Make in Pakistan Hackathon"

March 27-28, 2021  
(tentatively scheduled)

NIC, Lahore at LUMS

## Patent Approved!



**Dr. Wasif Tanveer**, an Assistant Professor at Department of Electrical Engineering, just invented a new technology to beam microwaves!

Syed Babar Ali  
School of Science and Engineering

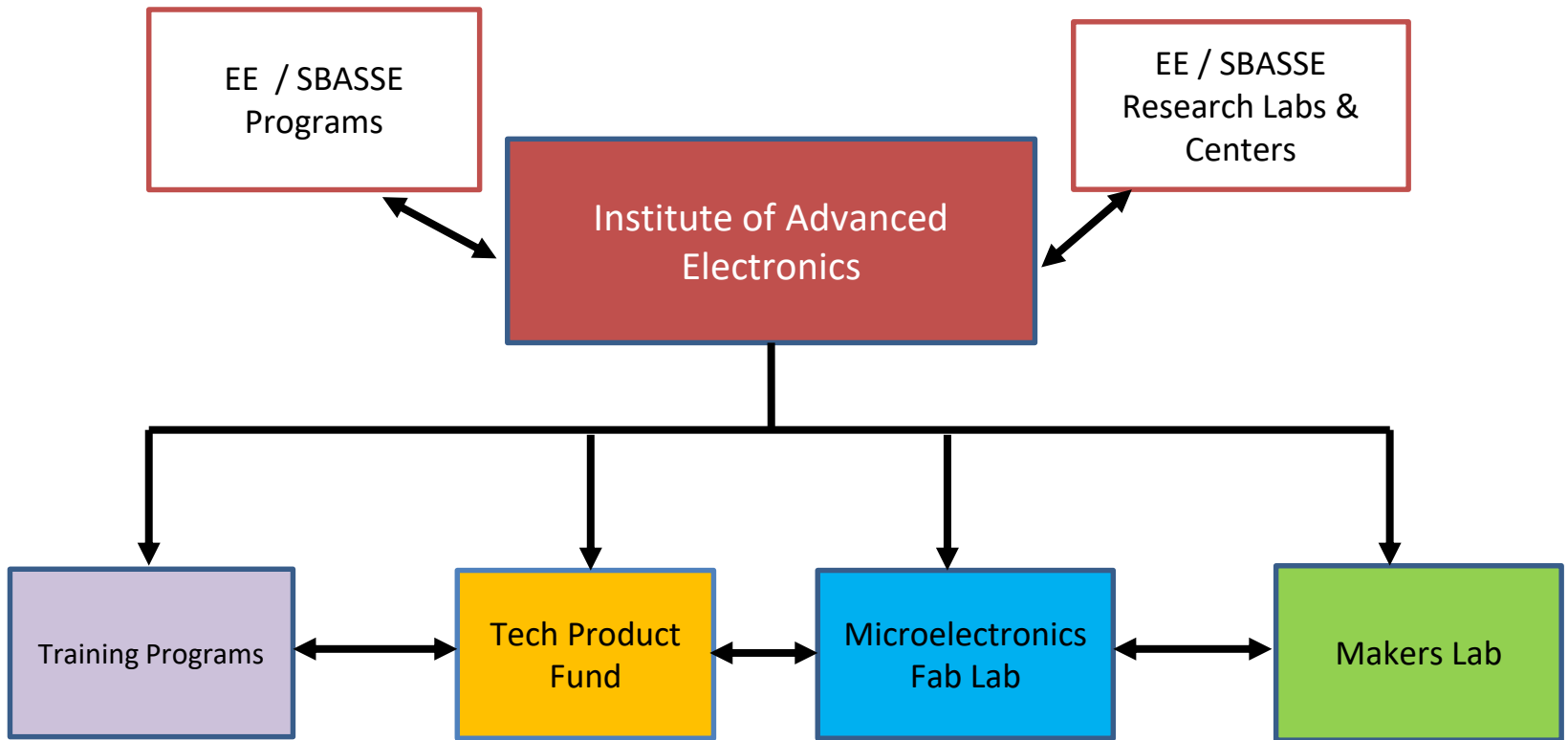
Dr Wasif Khan (lead)  
and **several others** from  
EE and CS Departments.





# Industry Partnerships

- Where are we going with this?
  - A future **Institute of Advanced Electronics**



# Student achievements

- Students got placed at **MIT two years in a row**
- **>25%** secured **funded PhD** positions @ top schools
- **>80%** acceptance rate @ top schools for batch 2020
- **1<sup>st</sup> Female PhD graduate** got **post-doc @ Stanford**
- No major COVID-impact on employment numbers
  - BS 92% placed after 6 months
  - MS 91% placed after 6 months



# Battery-Free Subsea Internet of Things

How a scalable underwater sensor network, which is entirely battery-free, has the potential to monitor the world's oceans.

By Sayed Saad Afzal

DOI: 10.1145/3436203

**R**ecently, there has been significant interest in low-power, low-cost scalable underwater networking systems for environmental, defense, and industrial applications. Driven by the need to address the impact of climate change, climatologists and oceanographers are interested in monitoring vital ocean signs such as coral reef conditions, biodiversity, and carbon balance. Similarly, the Defence Advanced Research Projects Agency (DARPA) launched the “Oceans of Things” program

in 2017 to move toward their goal of achieving an energy-efficient underwater networking system for maritime situational awareness. On the industrial front, top companies, such as Google, Microsoft, and Honeywell, seek to deploy such networks to monitor underwater structures ranging from oil and gas pipelines to submerged data centers.

In spite of growing interest and potential in this domain, existing solutions for a low-cost and low-power distributed underwater sensor network remain largely inadequate. This is because today's underwater systems rely on point-to-point communication that is power hungry (consuming 50–100 Watts for transmission). As a result, batteries of underwater sensors

get drained quickly. They would need to be recharged every time they run out of energy, which limits their lifetime. One workaround to this issue is to use duty cycling where sensors are powered up for only a fraction of the total time, and repeat this process to transmit data. However, this approach will severely limit our throughput to a measly ten bits per second.

So that leads to the following question: Is it possible to create a scalable underwater sensor network that is entirely battery-free, yet offers high data rates at a considerable operational range? The short answer is yes.

**COMMUNICATING WITH BACKSCATTER**  
Student researchers at MIT have developed an underwater sensor design

that employs “backscatter,” which allows for communication with 1 million times less power (ranging from 120uW to 500uW) than traditional underwater communication systems (see Figures 1 and 2). Backscatter sensors communicate at near-zero power by simply harvesting energy from ambient signals in the environment and then reflecting them back for communication. This makes them an ideal choice for ultra-low-power networks. Unfortunately, existing backscatter systems work with radiofrequency signals and these signals quickly attenuate underwater, which means these systems cannot be used for underwater communication or power harvesting. Instead, our sensors rely on acoustic signals for backscatter,

Image by Christian Palmer / Alamy

The Economist

Menu

Weekly edition

Search

Science & technology

Oct 17th 2020 edition

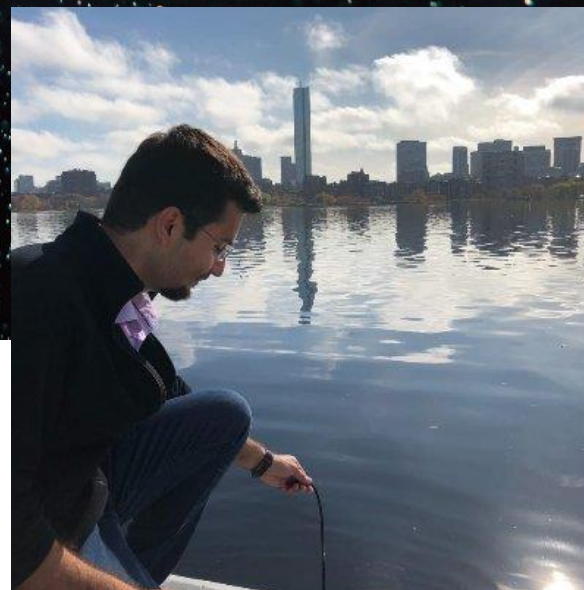
Good vibrations

## How to send underwater messages without batteries

A new device extracts energy from ambient noise



Jimmy Day



## Sayed Saad Afzal

EE Graduate 2018 batch – Gold Medalist

PhD Candidate, Fall 2019,

Massachusetts Institute of Technology, USA



# Sample SPROJ – 2019 Batch :



## High Voltage Conversion, Bi-Directional DC Microgrid



Awais Raza



Kashaf Jamshed



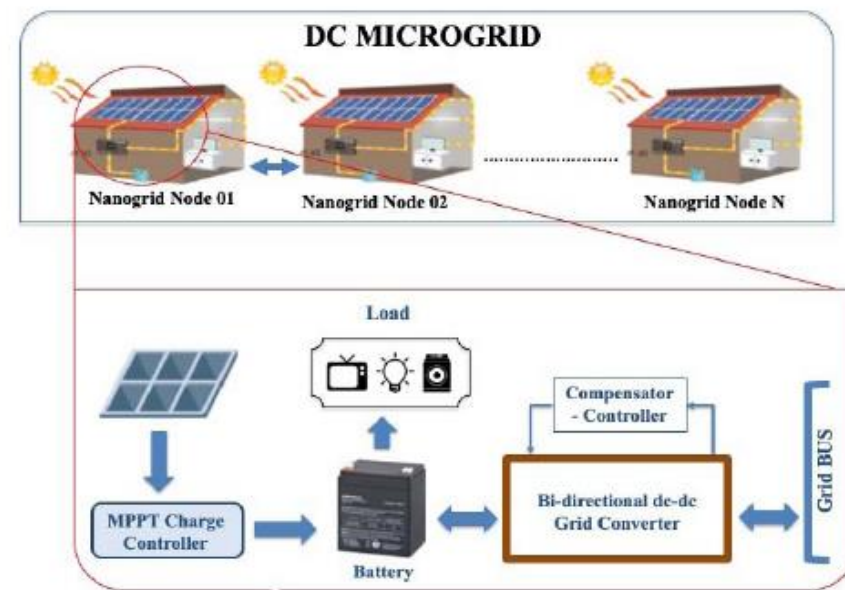
Maida Farooq



Prof. Nauman Zaffar



Dr. Hassan Abbas Khan




Simulation / Design (Diagram)

# THE PHD REVOLUTION

**IN SYED BABAR ALI SCHOOL OF SCIENCE AND ENGINEERING: "19 STUDENTS" GRADUATE IN 6 MONTHS FROM ALL DEPARTMENTS.**

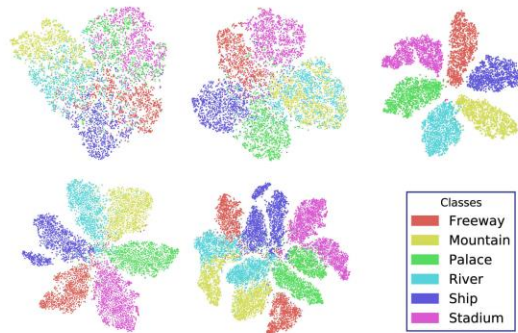
FROM PLACENTAL CELLS TO EDGE COMPUTING, FROM BRICK-KILNS TO CANCER TARGETING DRUGS, POWERING DISCOVERY AND INVENTION.



**LUMS**  
A Not-for-Profit University

## CORRELATING IMAGERY FROM THE SKY AND THE EARTH USING MACHINE LEARNING

PhD work emanating from SSE

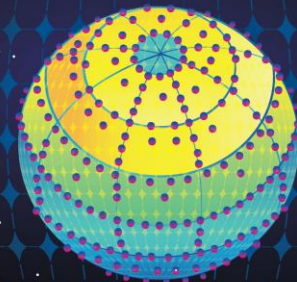


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## MUSIC OF THE SPHERES:

**Wajeeha Nafees** defends her doctoral work on acquiring signals from spherical sources and novel techniques of representing them.



Syed Babar Ali  
School of Science and Engineering

## AGRIVOLTAICS: THE SUN FOR FOOD

HASSAN IMRAN'S PHD WORK FOCUSES ON DESIGN OF SOLAR CELLS AND INTEGRATING THEM FOR ENHANCING AGRICULTURAL PRODUCE.



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## EE PhD graduates in 2020

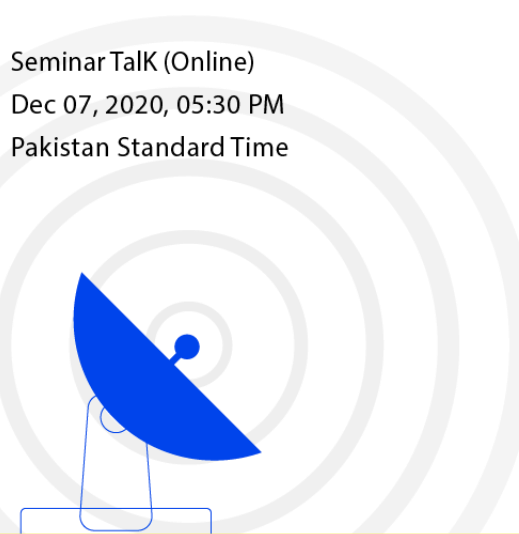
Saad Zia Sheikh (Dr Adeel Pasha)  
Muhammad Kamran (Dr Faryad)  
Numan Khurshid (Dr Murtaza Taj)  
Wajeeha Nafees (Dr Zubair Khalid)  
Hassan Imran (Dr Nauman Butt)



Micro Doppler Signatures and Multi-Antenna Radars:  
Research Directions, Challenges and Opportunities

Dr. Ijaz Haider Naqvi (Associate Professor, LUMS) and  
Dr. Faran Awais Butt (Assistant Professor, UMT, Lahore)

Seminar Talk (Online)  
Dec 07, 2020, 05:30 PM  
Pakistan Standard Time



LUMS

Department of  
Electrical Engineering



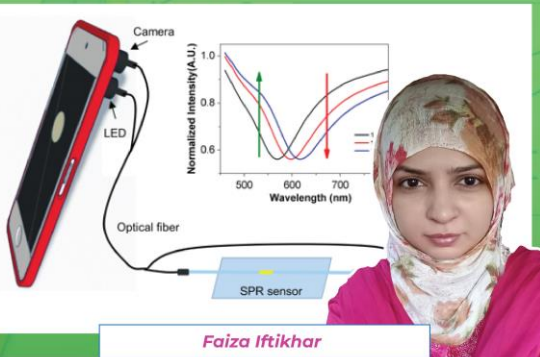
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Dr. Imran Cheema

Syed Babar Ali Research Awards  
2020

Bringing lab tests home



Faiza Iftikhar



Syed Babar Ali  
School of Science and Engineering

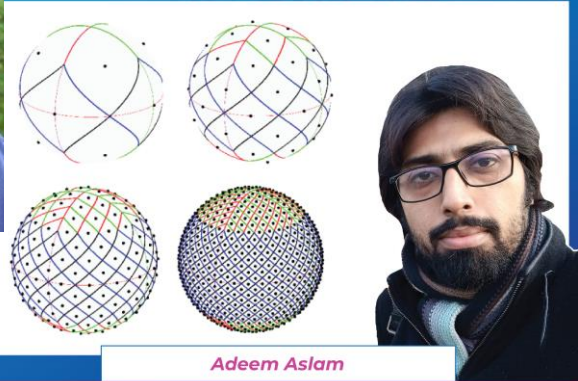
PhD student excellence

Syed Babar Ali Research Awards  
2020

Music, Wifi and The Big Bang



Dr. Zubair Khalid



Adeem Aslam



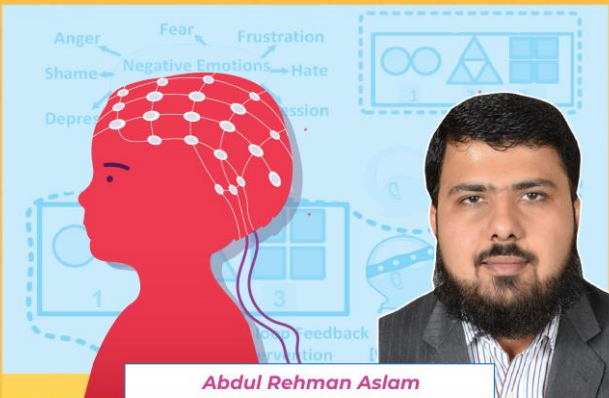
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Dr. Awais Bin Altaf

Syed Babar Ali Research Awards  
2020

Tracking human emotions



Abdul Rehman Aslam



Syed Babar Ali  
School of Science and Engineering



# Selected Research Highlights



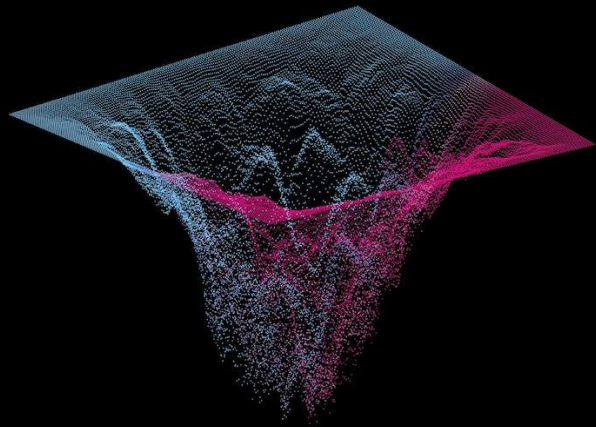
November 2020 | Volume 108 | Number 11

## Proceedings OF THE IEEE

SPECIAL ISSUE

### Optimization for Data-Driven Learning and Control

Scanning Our Past: The Bell Versus Gray Telephone Dispute: Resolving a 144-Year-Old Controversy



## Distributed Optimization for Robot Networks: From Real-Time Convex Optimization to Game-Theoretic Self-Organization

*This article presents a collection of state-of-the-art results for distributed optimization problems arising in the context of robot networks, with a focus on two special classes of problems, namely, real-time path planning for multirobot systems and self-organization in multirobot systems using game-theoretic approaches.*

By HASSAN JALEEL<sup>✉</sup>, Member IEEE, AND JEFF S. SHAMMA<sup>✉</sup>, Fellow IEEE

**ABSTRACT** Recent advances in sensing, communication, and computing technologies have enabled the use of multirobot systems for practical applications such as surveillance, area mapping, and search and rescue. For such systems, a major challenge is to design decision rules that are real-time implementable, require local information only, and guarantee some desired global performance. Distributed optimization provides a framework for designing such local decision-making rules for multirobot systems. In this article, we present a collection of selected results for distributed optimization for robot networks. We will focus on two special classes of problems: 1) real-time path planning for multirobot systems and 2) self-organization in multirobot systems using

game-theoretic approaches. For multirobot path planning, we will present some recent approaches that are based on approximately solving distributed optimization problems over continuous and discrete domains of actions. The main idea underlying these approaches is that a variety of path planning problems can be formulated as convex optimization and sub-modular minimization problems over continuous and discrete action spaces, respectively. To generate local update rules that are efficiently implementable in real time, these approaches rely on approximate solutions to the global problems that can still guarantee some level of desired global performance. For game-theoretic self-organization, we will present a sampling of results for area coverage and real-time target assignment. In these results, the problems are formulated as games, and online updating rules are designed to enable teams of robots to achieve the collective objective in a distributed manner.

**KEYWORDS** Convex functions; distributed algorithms; multi-robot systems; optimization.

### I. INTRODUCTION

In multirobot systems, a group of individual robots seeks to achieve a collective objective [1]. Motivating applications include collaborative missions, such as exploration [2], area coverage and monitoring [3], [4], task allocation [5], transport [6], and pursuit evasion [7], [8], as well



Dr. Hassan Jaleel

Manuscript received December 22, 2019; revised May 3, 2020 and August 25, 2020; accepted September 17, 2020. Date of current version October 27, 2020. (Corresponding author: Jeff S. Shamma.)

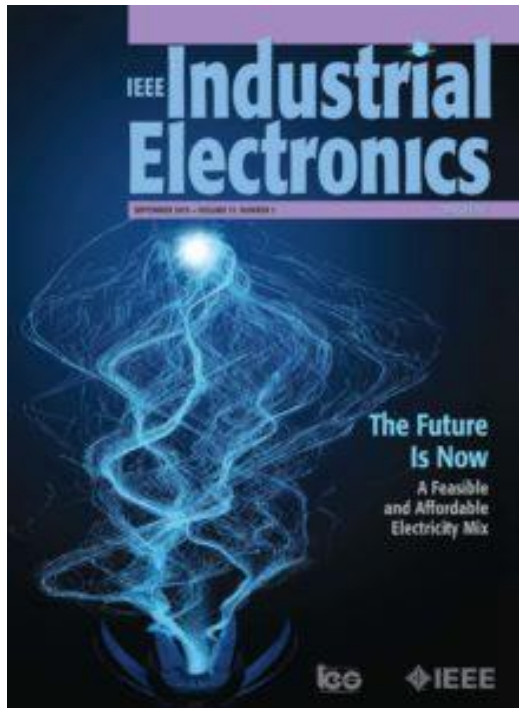
Hassan Jaleel is with the Intelligent Machines and Sociotechnical Systems (IMASS) Laboratory, Department of Electrical Engineering, Syed Babar Ali School of Science and Engineering, Lahore University of Management Sciences (LUMS), Lahore 54792, Pakistan (e-mail: hassan.jaleel@lums.edu.pk). Jeff S. Shamma is with the Robotics, Intelligent Systems, and Control (RISC) Laboratory, Computer, Electrical and Mathematical Sciences and Engineering (CEMSE) Division, King Abdullah University of Science and Technology (KAUST), Thuwal 23955-6900, Saudi Arabia (e-mail: jeff.shamma@kaust.edu.sa).

Digital Object Identifier 10.1109/PROC.2020.3028295

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Vol. 108, No. 11, November 2020 | PROCEEDINGS OF THE IEEE 1953

# Selected Research Highlights



## Blockchain Technologies for Smart Energy Systems

*Fundamentals, Challenges, and Solutions*



Dr. Naveed ul Hassan

NAVEED UL HASSAN, CHAU YUEN,  
and DUSIT NIYATO

**I**n this article, we discuss the integration of the blockchain into smart energy systems. We present various blockchain technology solutions, review important blockchain platforms, and describe several block-

chain-based smart energy projects in different domains. The majority of blockchain platforms with embedded combination of blockchain technology solutions are computing- and resource-intensive and, hence, are not entirely suitable for smart energy applications. We consider the requirements of smart energy systems and accordingly identify appropriate blockchain technology solutions for smart energy applications. Our analysis can help in the development of flexible blockchain platforms for smart energy systems.

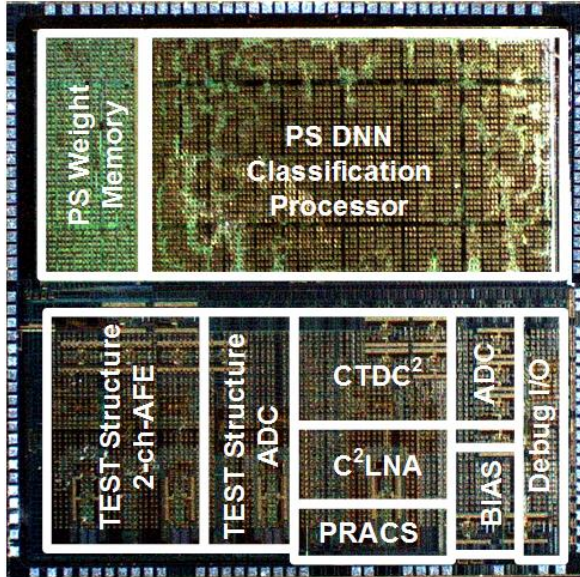
### The Potential for Blockchain Applications

The continuous expansion of smart energy systems for industrial, commercial, and domestic applications presents several new challenges and opportunities [1], [2]. Smart infrastructure (SI), renewable energy sources (RESs), and electric vehicles (EVs) are becoming widespread [3], [4]; energy and carbon trading possibilities are increasing [5]–[7]; and energy management (EM) through demand-response management (DRM) programs is becoming more common

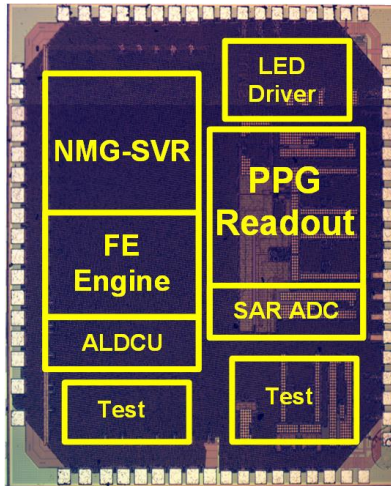
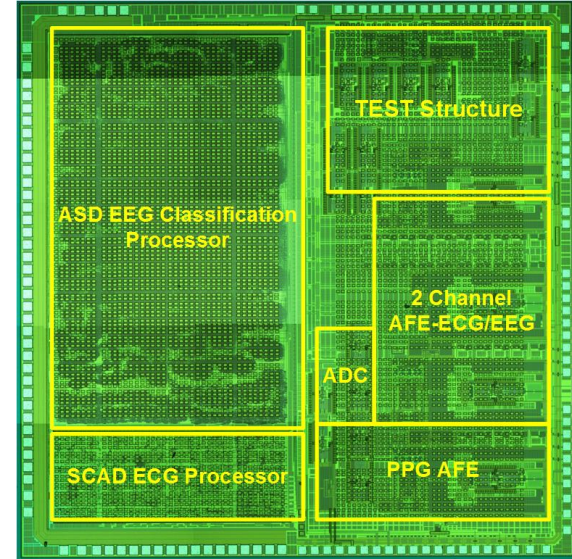
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Date of current version: 23 December 2019



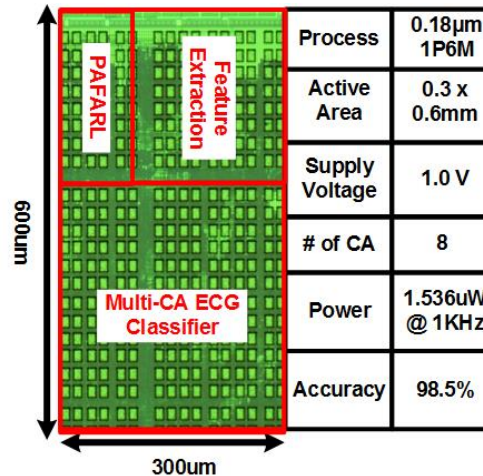
# Selected Research Highlights



Implemented Results	
Process	TSMC 0.18um 1P6M CMOS
Area	4.0 x 4.0 mm
Supply Voltage	1.0V (AFE) 1.0V (DBE)
NEF/channel	2.71
Classifier	DNN
Energy Efficiency	10.13uJ/Class.
Accuracy	85.2%
No. of Classes	4
PS Weight Memory	16KB



Implemented Results	
Process	180nm
Technology	NIR-PPG with NMG-SVM
Area	2.0 x 3.0 mm <sup>2</sup>
Supply	1.1V
Power	186μW
Duty Cycle	0.125%
I <sub>in, maxDC</sub>	65μA
Integrated RTI Noise	9.4pA <sub>rms</sub>
Gain	120dB
mARD	5.2% (200 Subjects)



**First ever indigenous chip design and tape out from Pakistan.**





### A Volunteer Supported Fog Computing Environment for Delay-Sensitive IoT Applications

Bahar Ali, Muhammad Adeel  
Houbing Song, Senior Member

**Abstract**—Fog Computing (FC) has emerged as a complementary solution to the centralized cloud infrastructure. FC node is available in closer proximity to users and cloud services to the edge of the network in a highly distributed manner. However, with an increase in streaming and sensitive Internet of Things (IoT) applications, FC also addresses the issue of higher latency while forwarding computation-intensive jobs to remote cloud data centers. Hence, there is a need to investigate the use of computational resources at the edge of the network. Volunteer Computing (VC) offers a reduction in cost of maintaining high-performance computing by making use of user-owned underutilized or idle resources, e.g., laptop/desktop computers closer to fog devices. We propose Volunteer Supported Fog Computing (VSFC), as a computing paradigm that explores the idleness of these two distributed computing domains to help minimize inherent communication delay, cloud computing, energy consumption, and network usage. In this effect, we have extended the FogSim toolkit to an VSFC. Extensive simulations show that VSFC outperforms traditional FC-cloud computing by reducing delay by 47.5%, energy by 93%, and network usage by 92% under normal to heavy conditions.

**Index Terms**—Distributed Computing Paradigms, Internet Things, Fog Computing, Volunteer Computing, Cloud Computing, Resource Management

#### I. INTRODUCTION

The plethora of smart devices has encouraged the industry and research communities to envision the beauty of mobile and taking precautionary measures in advance to save it of resources. In this regard, the Internet of Things supports the phenomenon of connecting every object or face of Earth irrespective of its platform, communication technology, etc. [1]. The IoT environment comprises of all that can be your wearables (smartwatches, glasses, etc.), vehicles (autonomous cars, smart bikes, etc.), fun time gadgets

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Bahar Ali is with the Department of Computer Science, School of Science and Engineering, Lahore University of Management Sciences (LUMS), 54792, Lahore, Pakistan; e-mail: 17193032@lums.edu.pk. Muhammad Adeel Pasha is with the Department of Electrical Engineering, School of Science and Engineering, Lahore University of Management Sciences (LUMS), 54792, Lahore, Pakistan; e-mail: adeel.pasha@lums.edu.pk. Houbing Song is with the Department of Electrical Engineering, Computer Science, Tsinghua University, Beijing 100084, China; e-mail: songh@sem.tsinghua.edu.cn. Color versions of one or more of the figures in this article are available online at <http://ieeexplore.ieee.org>.

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### Optimizing Hardware Accelerated General Matrix-Matrix Multiplication for CNNs on FPGAs

Afzal Ahmad<sup>1</sup> and Muhammad Adeel Pasha<sup>2</sup>

**Abstract**—Convolution is arguably the most complex operation utilized in Convolutional Neural Networks (CNNs). Owing to the billions of independent multiply-adds involved, convolution is being massively parallelized by the simultaneous utilization of many cores of Graphical Processing Units (GPUs). Although GPUs have shown significant performance improvements in both training and inference stages, they are not well-suited for mobile vision applications where both energy and real-time constraints need to be satisfied. In contrast, Field Programmable Gate Arrays (FPGAs) have demonstrated massive parallelization capabilities, with fast DSPs and on-chip memory, at a lower energy cost than GPUs. Hence, they are being utilized to design custom accelerators for embedded applications. In this brief, we design an FPGA-based accelerator for general matrix-matrix multiplication (GEMM) to improve the efficiency of convolutional layers of ShuffleNet, an efficient CNN architecture. Experimental results show significant performance improvements against the state-of-the-art FPGA-based implementations of both efficient convnets that are tailored towards mobile vision applications, and complex convnets that are used in traditional applications.

**Index Terms**—Hardware acceleration, FPGAs, convnets.

#### I. INTRODUCTION

CONVOLUTIONAL Neural Networks (convnets) have established themselves as the de-facto standard for several applications in the domain of computer vision such as image classification, object detection, semantic segmentation, and generative modeling. While the accuracy of convnets is improving at an unprecedented rate owing to the increasing ability to train deeper networks with larger datasets, their computational complexity is proportionally increasing to meet the demands for improved accuracy for use in critical applications such as self-driving vehicles. Graphical Processing Units (GPUs) have demonstrated high performance on convnets due to their parallelization capabilities, but their generality and high power consumption limit them. One the other hand, Field Programmable Gate Array (FPGA)-based hardware accelerators are being utilized to design custom architectures, exploiting their massively parallel and pipelined logic resources, and fast on-chip memory.

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Convnet architectures for mobile vision applications are focusing on decreasing the cost of convolutional (conv) layers due to their high computation complexity. Modern state-of-the-art convnets for mobile vision applications are utilizing depthwise, pointwise, and grouped convolutions to reduce network complexity and model size while maintaining high accuracy [1], [2]. Unfortunately, research in convnet architectures for mobile vision applications is not proceeding as rapidly as research in denser and more complex convnets aimed at improving accuracy. Therefore, as modern convnets tend towards deeper topologies trained on large datasets, there is a need to design efficient hardware accelerators that meet both energy and real-time computation constraints for mobile vision applications. In this brief, we design an FPGA-based accelerator for general matrix-matrix multiplication (GEMM), a key operation utilized extensively in convnets. As a use-case, we apply our accelerator to improve the performance of convolutional (conv) layers of ShuffleNet-v1 [2], an efficient convnet architecture. The main contributions of this brief are as follows:

- We design an FPGA-based hardware accelerator for GEMM by pipelining and parallelizing computational workload across available resources.
- We optimize our hardware accelerator to map conv layers of ShuffleNet onto the GEMM engine efficiently.
- We compare the performance of our accelerator system with several state-of-the-art FPGA-based solutions for both high-complexity and efficient convnet architectures.

#### II. RELATED WORKS

Pun et al. [3] designed an FPGA-based object-detection accelerator for SSD-NetM2, utilizing several hardware optimizations, and achieving 65 frames per second (fps) on a Zynq-7000 SOC. Su et al. [4] proposed redundancy-reduced and mobility, yielding significantly lower memory and computational complexity of the model compared to baseline mobilenets [1], and achieving inference time of only 7.85 ms on an UltraScale+ FPGA platform. Ding et al. [5] designed an accelerator system for depthwise separable convolution, achieving 17.6x speedup over a TriNetX GPU-based implementation. Xiao et al. [6] proposed a fusion architecture to fuse layers of convnets to allow reuse of intermediate data while also utilizing Winograd minimal filtering to reduce resource utilization, testing their design on both VGG16 and AlexNet. Mostofi et al. [7] proposed a resource-efficient accelerator, exploiting parallelism and reuse to reduce bandwidth, resource, and power consumption.

Owing to different types of convolutions involved in these efficient convnet architectures—including standard, grouped,

### A Dynamic Cache-Partition Scheduling Analysis for Partitioned Scheduling on Multicore Real-Time Systems

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**Abstract**—Recent integration of the cache-partition model has ushered in new paradigms of assessing the predictability and schedulability analysis for real-time systems. However, simply in the analysis framework has prompted existing contributions to be biased towards a static cache-partitioning scheme. The dynamic scheme has largely been criticized despite its proficiency in schedulability, flexibility, and energy efficiency. In this letter, we address the latter problem and make initial contributions to a dynamic cache-partition scheduling analysis for real-time partitioned scheduling of real-time fixed-priority aperiodic tasks. We devise a sufficient schedulability test and then refine the upper-bound by proposing techniques to reduce the pessimism in the interference caused by cache contention.

to have an adverse impact on the energy efficiency of the system and a attempt have been made to adapt a dynamic CP scheme into partitioned scheduling where the CPs are dynamically allocated to the cores. However, such initiatives are limited to simpler frame-based tasks [2] and integer linear program (ILP) formulations [3]. The dynamic CP scheme has been exclusively used in global scheduling. In traditional global scheduling, tasks are dynamically allocated to cores. This can theoretically increase the schedulability, however, schedulability tests for global scheduling algorithms are largely pessimistic since the critical instant of a task  $\tau_i$  is unknown which specific sequence of its tasks (HPTs) will lead to the maximum response time. This is an upper-bound on the interference from HPTs is missed via the problem instance approach, where a task  $\tau_i$  is assumed to have missed its deadline and the maximum from its HPTs, that led to its deadline miss, is then used to determine its schedulability [4]. These schedulability tests have been extended into the CP-scheme.

### FFConv: An FPGA-based Accelerator for Fast Convolution Layers in Convolutional Neural Networks

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Image classification is known to be one of the most challenging significant research is being done on developing systems and algorithms, and power consumption for related problems. Convolution gives outstanding accuracies for problems such as image classification. While CNNs are pioneering the development of high-level complexity presents a barrier for a more permeated deployment (GPUs), due to their massively parallel architecture, have shown better than general purpose processors, the former are limited by the Consequently, Field Programmable Gate Arrays (FPGAs) are being as they also provide massively parallel logic resources but with GPUs. In this article, we present FFConv, an efficient FPGA-based CNNs. We design a pipelined, high-throughput convolution engine (also called Fast Convolution) algorithms for computing the architectures VGG16, AlexNet, and ShuffleNet. We implement where we exploit the computational parallelization to the maximum improving performance. The resultant design uses only 0.3%, 0.4%, for VGG16, AlexNet, and ShuffleNet-v1, respectively, while significant power efficiency compared to previous state-of-the-art designs.

CCS Concepts: • Hardware → Hardware accelerators;

Additional Key Words and Phrases: FPGA, convolutional neural

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#### 1 INTRODUCTION

With the advent of Artificial Intelligence (AI), the popularity of Deep Neural Networks (DNNs) has exploded in the past few years with applications in various domains such as image and speech pattern recognition to natural language processing. Convolutional Neural Networks (CNNs) are

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### Energy-efficient Real-time Scheduling on Multicores: A Novel Approach to Model Cache Contention

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adoption of multicore has been a major stepping stone in the computational bandwidth is increased due to the hierarchical memory sub-system and multiple execution time (WCET) analysis of tasks. Furthermore, the inclusion of shared caches further increases the complexity of the scheduling problem.



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