# Industrial Applications of Control Systems and Signal Processing

Report on Short Term Course

Submitted to
TEQIP-III, IIT Indore,
Simrol, Indore, Madhya Pradesh


Submitted by

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## Event summary:

As part of research outreach to faculties, industrial practitioners and students, a short term course on 'Industrial Applications of Control Systems and Signal Processing' was organized between 19-24 Aug. 2019 at Indian Institute of Technology Indore (IIT Indore), Indore, Madhya Pradesh, India. The course was sponsored by Technical Education Quality Improvement Programme, Phase III (TEQIP-III) of National Project Implementation Unit (NPIU). The course included several lectures delivered by expert speakers from IIT Indore and outside. The participants mostly came from TEQIP-III funded institutions.

## Motivation of the course:

Industrial systems/processes are designed to show some specific response to perform a preassigned task. However, the response generally varies from the expectations due to several physical and non-physical factors. Control systems are used to regulate the system/process to provide the desired response. The signal processing independent of the control systems is used for analysis and synthesis of signals. The signals are essential to convey information about the variation of several physical phenomena. Both the control systems and signal processing are extensively used in modern industrial applications. The broad applicability of classical control systems includes unmanned vehicles and network control to ease busty traffic. Modern control systems based on state space model have further helped in dealing with several industrial challenges, e.g. tracking of objects (like vehicle, satellites, enemy warheads etc.), forecasting of several physical phenomena (especially related to weather and finance), stochastic modeling using parameter estimation. On the other hand, the signal processing has enhanced the performance of several systems/processes due to the accurate collection of information. A simple example can be considered as processing of biomedical signals (like ECG and EEG signals) for accurate diagnosis of heart and brain-related disorders.

The motivation of this course was to discuss about the recent uses of control systems and signal processing in industrial problems associated with several engineering domains like the Electrical Engineering, Mechanical Engineering and Biomedical Engineering. The motivation was also to discuss about the developments/results related to futuristic use of control systems and signal processing in emerging problems of science and technology.

## Objective and features:

With the above motivation, the objective of the course was to discuss the applications of control systems and signal processing in solving real-life scientific and engineering problems. The scope of the discussion included their applications in Electrical Engineering as well as other important streams like the Mechanical Engineering and Biomedical Engineering. The course feature included a series of expert lectures, and an opportunity of having an open discussion with the speakers. The discussion hours were opened at the end of lectures as well as during the tea breaks.

## Questions- explored and answered:

1. Why do we need control systems and signal processing?
2. What are some recent developments in control systems and signal processing?
3. How control systems and signal processing have been used to enhance different domain of science and technology?
4. What are some recent areas of science and technology where control systems and signal processing are being explored, and in what potential they can be improved?
5. What academicians think about the future of control systems and signal processing?

## Targeted beneficiaries:

1. UG and PG students of Electrical Engineering, Electronics Engineering, Instrumentation and Control, Biomedical Engineering, Aerospace Engineering, and related areas.
2. PhD students with expertise in control systems, signal processing, mathematics and computation, machine learning, biomedical signal processing, biomedical modeling *etc*.
3. Faculty members with above discussed specialization.
4. Industry experts involved with control systems and signal processing related applications.

## Participant registration:

A total of 34 participants registered for attending the course, however some of them were absent during the course. The registration was received from the participants at various levels including 3$^{rd}$ and 4$^{th}$ year undergraduate, postgraduate, PhD and faculties. The participants came from various parts of India including the states like Orissa, Bihar, Madhya Pradesh, Goa and Rajasthan.

## About the coordinators:

*Dr. Abhinoy Kumar Singh:* He received his Ph.D. degree in Electrical Engineering from IIT Patna, India, in 2016. During the PhD, he worked on algorithm development for estimation and filtering. He did his postdoctoral research from McGill University, Canada which is ranked at 31 in QS world ranking. During the postdoctoral research, he worked on developing a continuous glucose monitoring (CGM) system which is part of an underdeveloped artificial pancreas. An accurate CGM system is expected to ease type-1 diabetes treatment by providing better glucose management in patient's body. He is currently working in the Discipline of Electrical Engineering, IIT Indore, as an Inspire faculty.

*Prof. Ram Bilas Pachori:* He received the Ph.D. degree in Electrical Engineering from IIT Kanpur, India, in 2008. He worked as a Postdoctoral Fellow at University of Technology of Troyes, France during 2007-2008. He served as an Assistant Professor at Communication Research Center, IIIT Hyderabad, India during 2008-2009. He served as an Assistant Professor in the Discipline of Electrical Engineering, IIT Indore, India during 2009-2013. He worked as an Associate Professor in the Discipline of Electrical Engineering, IIT Indore, India during 2013-2017 where presently he has been working as a Professor since 2017. He is also a Visiting Professor at School of Medicine, Faculty of Health and Medical Sciences, Taylor´s University, Subang Jaya, Malaysia since December 2018. He worked as a Visiting Scholar at Intelligent Systems Research Center, Ulster University, UK during December 2014. He is an Associate Editor of Electronics Letters, Biomedical Signal Processing and Control journal and an Editor of IETE Technical Review journal. He is a senior member of IEEE and a Fellow of IETE. He has more than 160 publications which include journal papers, conference papers, books, and book chapters.

## Lecture title and abstract:

### Lecture: 1

*Speaker:* Prof. Pradip Sircar

*Title of talk 1:* Mathematics in Signal Processing and Control

*Abstract:* In this talk, we explore the connection between Mathematics and Signal Processing, where it is explained how mathematical concepts are moulded into mathematical methods, and mathematical methods perform signal processing tasks. The methodology has been illustrated through a case study of spectral estimation of a signal, and various mathematical tools used for the task are investigated to understand the underlying mathematical concepts.

*Title of talk 2:* Speech Compression: Model-based Speech Processing

Abstract: In this presentation, we discuss a classic example of model-based signal processing. The sinusoidal model is fitted to the speech signal, and the processes of analysis and synthesis of the signal have been demonstrated. We then systematically explore redundancy of information in the model parameters and reduce the set of essential parameters to an irredundant level. The design of a low bit-rate speech coder has been illustrated in the procedure.

**Lecture: 2**

*Speaker:* Dr. Santosh Kumar Vishvakarma

*Title of talk:* AI Chips/Hardwares for Intelligent Systems

*Abstract:* AI chips/hardwares have played pivotal role in development of several cutting age tools and technologies. This lecture will discuss about some major AI chips/hardwares. The discussion will be extending on the capabilities of AI chips/hardwares for industrial purpose. We will also discuss about the sectors that will be forced to adopt the AI chips/hardwares. We will conclude the discussion with suggestions to business leaders that they must do to be prepared with innovation in AI chips/hardwares.

**Lecture: 3**

*Speaker:* Prof. Anand Parey

*Title of talk:* Applications of Signal Processing Techniques in Fault Detection of Mechanical Systems

*Abstract:* Gearboxes have an important role in power transmission systems. For such systems, vibration-based fault diagnosis techniques are frequently used to prevent premature failure and to ensure smooth transmission. This paper aims to automate the fault diagnosis of gears having wear fault at micron level using variational mode decomposition (VMD). VMD has been applied iteratively with specific input parameters. VMD decomposes the gear vibration signal into different narrowband components (NBCs). Various statistical features namely kurtosis, skewness, standard deviation, root mean square, and crest factor are extracted from the different NBCs. Kruskal-Wallis test has based probability values have been used to identify the significant features. For the automation of fault deduction system, a comparative study has been done using the random forest, multilayer perceptron, and J48 classifiers. The proposed method exhibits 96.5% accuracy using random forest classifier with combined kurtosis, skewness, and standard deviation features.

**Lecture: 4**

*Speaker:* Prof. Vimal Bhatia

*Title of talk:* Signal Processing Challenges for 5G and Beyond Communications

*Abstract:* With the emergence of the connected world with technologies like IoT, 5G and beyond, the talk was organised to give an overview of the technologies effecting our daily lives. A brief introduction to the world of communications including wireline, terrestrial wireless, optical and satellite was given. After the introduction, there were specialised talks on digital communication, visible light communication, cooperative communications, 5G and beyond technologies, and machine learning. The participants were introduced to these technologies with interactive mode with Q&A during and after the session.

**Lecture: 5**

*Speaker:* Prof. Ram Bilas Pachori

*Title of talk:* EEG Signal Processing for Medical Applications

*Abstract:* The electroencephalogram (EEG) signals are commonly used for measuring electrical activity of the human brain. These EEG signals contain a lot of useful information for diagnosis of various human brain disorders. In the recent years, our research group has developed methods based on non-stationary signal decomposition techniques and machine learning algorithms for analysis and classification of EEG signals. The empirical mode decomposition (EMD) has been proposed for analysis of normal and seizure EEG signals, classification of seizure and non-seizure EEG signals, and detection of epileptic seizures. The time-frequency image based features have been proposed for the classification of various sleep stages from EEG signals. The multi-wavelet transform based features have been proposed for classification of human emotions from EEG signals. These developed methods have been compared with the existing methods in the literature. In this talk, I have presented these above mentioned developed methods for analysis and classification of EEG signals.

**Lecture: 6**

*Speaker:* Dr. Pavan Kumar Kankar

*Title of talk:* Condition Monitoring of Bearing

*Abstract:* A wavelet based fault diagnosis methodology using various machine learning methods like support vector machine (SVM) and artificial neural network (ANN) is very effective in defect identification in bearings. This methodology incorporates most appropriate features, which are extracted from wavelet coefficients of raw vibration signals. Wavelet selection criterion Maximum Energy to Shannon Entropy Ratio is used and compared to select an appropriate wavelet for feature extraction. The wavelet selected using Maximum Energy to Shannon Entropy Ratio criterion (Meyer wavelet) gives better classification efficiency. The performance of SVM (classification efficiency 98.667 %) is found to be best due to its inherent generalization capability. By using wavelet based methodology, useful features can be extracted from the original data and dimension of original data can be reduced by removing irrelevant features, so that the classifier can achieve a higher accuracy. The study also shows trends of instability in a rotor bearing system for healthy and defective bearings.

**Lecture: 7**

*Speaker:* Dr. Mukesh Kumar

*Title of talk:* On-chip Devices for Optical Communication and Interconnects

*Abstract:* Introduction of Optoelectronics with its multidisciplinary applications is discussed. Design and fabrication of on-chip devices for optical communications are presented. Electrical control of on-chip photonic devices based on novel/hybrid materials is demonstrated. Some of the devices based on engineered silicon and graphene at micro- and nano-scales are presented for applications in optical interconnects.

**Lecture: 8**

*Speaker:* Dr. Abhinoy Kumar Singh

*Title of talk:* Kalman Filter based Continuous Glucose Monitoring Systems

*Abstract:* The talk describes the algorithmic aspect of a CGM system which is a part of an underdeveloped artificial pancreas and can be an efficient tool in the treatment of type-1 diabetes.

The type-1 diabetes is treated by managing the glucose concentration in normal range through external insulin injection. The time and amount of insulin injection is decided by monitoring the glucose concentration. The existing glucose meter based monitoring is very much inefficient and unreliable. To improve the efficiency and reliability, the CGM system is underdevelopment. The CGM system consists of a glucose sensor and an estimation algorithm to measure the glucose concentration. The sensor, in response to interstitial glucose concentration, generates a noisy electric current which is transformed to measure the glucose concentration. A major challenge in this transformation is time-varying sensor sensitivity that changes the current-glucose relation with time. To address the sensitivity variation in real-time, the algorithm is calibrated every 12-hour using capillary glucose measurement. The calibration is two-step process: (i) compartment matching, and (ii) parameter estimation. Both the steps poses an estimation problem which is dealt by using Kalman filter. The parameter estimation additionally requires precise knowledge of initial estimate and covariance of desired parameters which is obtained in offline analysis based nonlinear cubature Kalman filter.

**Lecture: 9**

*Speaker:* Dr. Shovan Bhaumik

*Title of talk:* Estimation and Filtering Theory with Application to Target Tracking

*Abstract:* Modern era of science and technology witnesses several problems where hidden or latent quantity/quantities is/are desired to be estimated from a set of noisy sensor measurements. A common example is tracking of a moving target whose trajectory must be inferred from the information collected by the sensing radars. The trajectory is characterized with the help of position along the axes. Modelling of the positions needs the knowledge of velocity and acceleration (only velocity in case of constant acceleration motion) as well. Therefore, the desired quantities become the position, velocity and acceleration. Despite of the desired quantities, the measurements collected from the sensing radars reveal the dynamics in terms of noisy range (radial position) and elevation angle. The technique used to compute the hidden quantities (the unobserved desired quantities, like the position, velocity and acceleration in case of tracking) using the noisy measurements is called estimation. A recursive implementation of estimation over a sequence of observed measurements is known as filtering. This lecture will discuss about the development of estimation and filtering theory, especially for nonlinear systems. Moreover, a detail discussion will be provided on the application of nonlinear filtering algorithms in dealing with challenging target tracking problems like the underwater tracking of enemy warship and ballistic missile tracking.

**Lecture: 10**

*Speaker:* Dr. Vivek Kanhangad

*Title of talk:* Automated Industrial Inspection Systems that Rely on Signal/Image Analysis

*Abstract:* Inspection systems are extensively used in manufacturing industries to examine the characteristics of the product and to compare with the specified requirements. Industrial inspection is a repetitive and often, a critical task. Manual operators are slow, expensive and unreliable. Therefore, automated inspection systems, which work around the clock and maintain a high level of consistency and quality, have replaced human operators. In this talk, I will discuss the significant role that automated inspection systems play at various stages in a manufacturing pipeline and present several examples. Further, I will discuss the classical methodology involved in the design of automated inspection systems. Recently, there has been a paradigm shift with machine learning techniques

playing a major role. Therefore, I will also introduce advanced machine learning techniques that can be used to design more efficient automated inspection systems.

**Lecture: 11**

*Speaker:* Dr. Rajeeb Dey

*Title of talk:* Modeling and Control of Artificial Pancreas: Emphasis on Observer based Control

*Abstract:* Blood glucose (BG) concentration in the blood plasma of a healthy person is regulated within a safe range of 70–180 mg/dl due to insulin secretion by the pancreas. When there is an autoimmune destruction of pancreatic β-cells, negligible or no such secretion takes place in human body, leading to a disease called type 1 diabetes mellitus (T1DM). To maintain appropriate level of glucose level in the blood plasma, patients rely on multiple daily insulin injections based on the glucose measurements carried out few days ago and not on the current level of the glucose for restoration of normal glucose concentration level. The manual (or open-loop), insulin therapy is based on irregular glucose measurement, thus at certain instances, due to improper insulin dosages, glucose concentration may be higher than normal level (hyperglycemia) or can drastically fall below normal level leading to hypoglycaemia. The hypoglycaemic situation in T1DM patients can cause hypoglycaemic coma and death, whereas hyperglycaemia can lead to long-term complications like cardiac arrests, leg amputations, renal failure, and diabetic retinopathy. Thus automatic control of glucose concentration in blood plasma is a challenging problem owing to various patient parameters that influence this phenomenon.

This talk is intended for engineers, practitioners, patients, care givers to understand the mechanism of diabetes diseases systematically and to get acquainted with the terminologies used for treating the disease. This talk can also be treated as an awareness program for the different sections of the society especially young generations as this disease is declared to be epidemic by WHO. The talk will reveal the need of engineers in developing control algorithms for artificial pancreas technology by bringing an analogy of the disease with an engineering automation problem. The level of the mathematics involved in the technology will be not be discussed in details though touched upon to realise the research issues involved in development the technology.

**Lecture: 12**

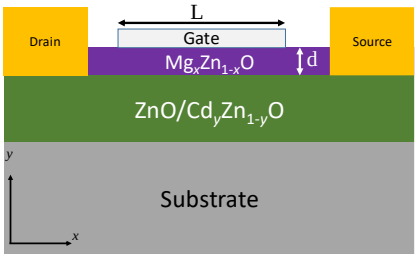
*Speaker:* Dr. Shaibal Mukherjee

*Title of talk:* Devices and systems for next-generation energy, RF, and non-volatile memory applications

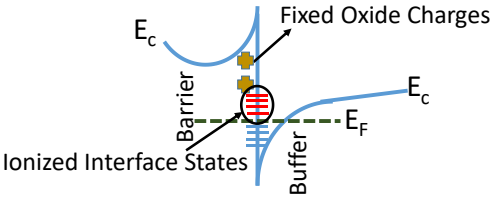
*Abstract:* Different materials are being explored as a viable option for heterostructure field effect transistor (HFET) or high electron mobility transistor (HEMT) application due to the strong polarization fields at the heterojunction interfaces. HEMT devices are enormously applicable for KW-level of power and 100s of GHz-level of frequency applications for various domestic, commercial, defence, space, and industrial applications.

Fig. 1 (a) shows schematic of the MgZnO/ZnO based heterostructure, utilized for analytical model development for HEMT application. Fig. 1(b) shows conduction band energy diagram of MgZnO barrier and ZnO buffer with positively ionized interface states and fixed oxide charges near the barrier-buffer interface, collectively termed as interface states density ($Q_i$). Fig. 1(c) shows drain current ($I_d$) with varying gate voltage ($V_g$) at constant drain voltage ($V_{ds}$) for constant value of $Q_i$ and for $Q_i$ modulating with $V_g$. It is observed that linearly modulating $Q_i$ provides significant agreement

with experimental $I_d$-$V_g$. Change in $Q_i$ in oxide-semiconductor interface with applied $V_g$ is a well-established phenomenon in literature. Fig. 1(d) shows $I_d$-$V_{ds}$ for varying $V_g$ from -1 V to 1 V, with and without linear $Q_i$ modulation with $V_g$. This model can be utilized for accurately analyzing and hence optimizing ZnO based HFETs grown by different deposition techniques.




(a)




(b)