Suggested PhD Project Topics
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This by no means is an exhaustive list and I am always open to novel project ideas proposed by prospective post-graduate research students providing that it falls in the research field of RPCS lab. Based on our established research track-record and industrial collaboration, I have listed some suggested topics below. The list may be updated in the near future.

ENERGY STORAGE

Condition monitoring system for EVs battery packs using heterogeneous current density images of LiB cells
Description: Improving the performance and lifetime of EVs LIB Packs is still a challenging problem. This will be achieved by obtaining a more accurate state-of-charge (SoC) estimation and reliable temperature monitoring. In this project a multi-physics sensor array will be developed using disruptive Graphene-based magnetometer sensors for the online monitoring of the in-situ current flow within individual Li-ion pouch cells. High-resolution sensor images are desired in real-time for the battery management systems (BMS) and conditional monitoring system (CMS) to allow higher life-cycle with instant cell-equalisation, predict thermal runaway, estimate accurate SoC/SoH measurement, avoid long-term degradation, improve the energy density, stabilise the power density and reduce the overall cost of the battery pack. This is a multi-disciplinary and industrial-based project. Please look at the research page for more details on my projects.

Improving the lifecycle of EV Battery Packs using Graphene-based sensors or wireless antenna
Description: Predicting the life cycle of LiB pack system in EVs is still a challenging problem for a vehicle manufacturer. With the current technology, nonlinear behaviour estimation and life cycle prediction of a single cell in real-time is not possible due to computational burden of the complex electrochemical models of batteries and the simplicity of the current equivalent circuit models (ECMs) suitable for control and online monitoring. The interconnection of cells in the pack makes such estimation even more difficult as the electrical dynamics and thermal characteristics of individual cells are different. This may introduce random variability and the fact that ageing of a single cell can propagate and reduce the life of the whole battery pack known as ageing propagation. This project investigates a Graphene-based sensor/antenna array and advanced battery models to provide critical battery parameters, i.e. temperature, internal resistance, chemical degradation, to the battery management system (BMS), and enhance the lifecycle of the battery packs in electric vehicles.

POWER ELECTRONICS

Project: Multiphysics sensor array for Silicon Carbide (SiC)-based power electronic converter prognostics in electric vehicles
Description: Power electronic converters (PECs) underpins modern electric and hybrid vehicles allowing efficient energy transfer between the vehicle battery system and the drive motors. To simplify construction, reduce costs and increase reliability, manufacturers are seeking ever-tighter system integration. However, this level of integration poses a number of significant challenges including interlinked heat transfer paths, bond wire lift-off and unwanted thermal stresses. In this project, we investigate a multi-physics sensor fusion technique to provide accurate prognostics for highly integrated SiC-based PECs. An intelligent vehicle management system will be implemented to adjust the available power and cooling requirements based on the real-time estimation of the true age and safe operating area of the PEC based on the online conditions and records of previous ageing. A sensing platform, i.e. an array of multi physical sensors, needs to be developed to quantify the health status of power electronic modules by generating an *image* of measurements which consist of temperature, electrical quantities (V, I, Z) and mechanical displacement (wire bond

movement/device deformity) on the power module. This is a multi-disciplinary and industrial-based project. Please look at my projects and labs pages for further details.

High Efficiency Power Electronic interface for Vehicle-to-grid (V2G) application
Description: The use of Electrical Vehicle (EV) battery pack to supply power to the grid (V2G) increases reliability and consistency in the grid as the renewable source, e.g. wind, solar, undergoes its natural fluctuations. Furthermore, power quality can be increased with having battery storage for charging/discharging electricity to the grid. V2G operation is generally using power electronic converters (dc-dc & VSC) and inverters to act as a bidirectional charger capable of charging and discharging the battery on demand while complying with grid standards. Commercial bidirectional chargers typically use conventional 2-level silicon-based PWM converter topologies able to switch at relatively low frequencies. As a result, compared to the size of the battery or EV, they are relatively bulky and suffering from significant power losses. This project is focused on modelling and designing more efficient power converters based on Silicon-carbide switching devices to reduce the size of bidirectional chargers and reduce the power losses. This is investigated via developing novel converter topologies and control strategies for the rapid response (low latency with high switching frequency) to the grid demand.

Silicon-Carbide-Based Power Electronics for Wave Energy Converters
Unlike fossil fuels, wave energy is clean, sustainable and causes no air pollution and noise. Compared with wind, solar and other RES, wave energy is also more steadily available and has denser energy concentration, which can be captured by wave energy converters (WECs). In this project, we will develop novel control approaches and state-of-the-art WEC power electronics to significantly improve the WEC overall performance so that LCOE of wave can be close to or even lower than that of solar. An integrated WEC will be designed using silicon carbide devices to increase switching speed (20KHz), blocking voltage capabilities and tolerance to junction temperature and the efficiency of the power output (> %98.5). The design must simplify the construction, reduce costs and increase temperature reliability (+40^{o}C) using a novel package. A real-time prognostic system is required to significantly increase the WECs calendar life, the reliability/quality of the output voltage and overall stability of the power output if an array of WEC is employed in a microgrid (MG) system. This project is sponsored by EcoWavePower developed ground-breaking on-shore economical WEC systems.

ENERGY EFFICIENCY IN BUILDING ENVIRONMENT

Residential Load Forecasting for Individual Appliances: Machine Learning Approach
Energy companies and government face challenges in successful smart meters roll-out where only ~50% of the planned smart meters are installed in homes in UK. Companies can hardly give any estimation to their customers or users that how much energy they will save in the future, and how they can translate the saving to money. To tackle this challenge, this project proposes a rather novel and practical approach based on machine learning techniques for the prediction of power consumption by the individual home appliances. Accurate prediction of power consumption can play an important role for power suppliers to predict electricity demand and prevent energy waste. In this project, we worked actively with the company, *Voltaware* Ltd, developing state-of-the-art real-time monitoring tools. We developed our prediction algorithms using their disaggregated power consumption data collected from three countries UK, Italy and France from 28 different households.

Wireless Energy Management in Home Environment using Situational Awareness
Description: Low-cost monitoring of energy usage and providing energy efficiency by a home energy management system (HEMS) is still a challenging problem considering the rise of household energy cost. Algorithms like situational awareness (SA) can be employed for the real-time scheduling, power distribution, and automation of wireless sensor network (WSNs) of home appliances/renewables. Such algorithms can provide a vision of the network events before the event occurs in a distributed

fashion. This project will investigate different machine learning (ML) techniques to learn the behaviour of home users using energy usage pattern data and to implement an intelligent agent for the SA-based HEMS system. The agent will make automated decisions to control the home renewable sources (wind/solar + batteries). Suitable communication system must be designed for the SA-based system architecture (see the figure below) including appropriate Communication protocol, security algorithms, and a design for the Ad-hoc network (MAC layer, Physical layer), and optimal Control/Adaptive Dynamic Programming (ADP) approaches may be employed for optimising the WSNs.

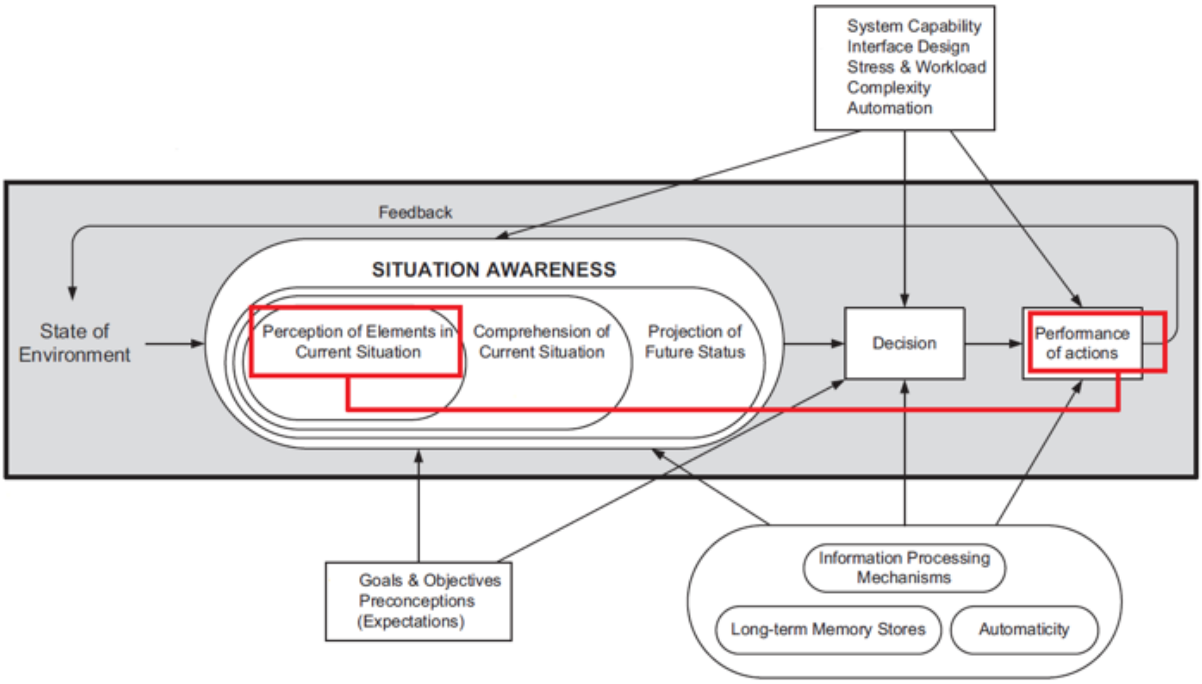

Figure – SA-based architecture for Home Energy Management System

ELECTRIC DRIVE-TRAIN AND PROPULSION SYSTEM

Advanced Electric Propulsion Management for Small Marine Vessels

Description: In UK small marine vessels vastly outnumber large marine vessels and collectively create far more pollution on a par with that from the respective Heavy Goods Vehicle population. Emissions may reach 17% by 2050 (European parliament report), and the resulting pollution (PM, NOx, SOx) contributes annually to 50,000 premature deaths in Europe costing society more than £50 billion (Transport & Environment NGO). Large marine vessels have already started benefitting from electric drivetrains reducing emissions and costs. However, the sector of smaller vessels has not adopted the technology due to the hurdle of 'no Regenerative Braking', well-known in Automotive Electric Vehicles. Moreover, the transient dynamics caused by large load variations in small ships seriously reduce the efficiency of the electric drivetrain and need specialised torque measurement techniques. The project objective is to develop a mathematical modelling framework for the mechanical marine propulsion system with the associated electric drive system (including electric motors) to create a complete electric drive system energised by batteries. Using the industrial collaborator's (DuodriveTrain, http://www.duodrivetrain.uk/) patented direct torque & thrust measurement technique, the project is aimed to develop novel predictive control/optimisation approaches to remove the transient dynamics in the electric drive trains including the electric machines. This will dramatically increase the electric drive propulsion efficiency in conventional as well as autonomous surface vessels, and improve battery life. The project results can be employed as a simulation platform for testing and evaluation of the electric drivetrains to reduce the significant time/cost of the experimental development and lab testing. Since the project is mainly based on mathematical analysis and simulation model development with Matlab/Simulink, the project is suitable for covid-19 lockdown constraints of accessing to the lab equipment.

WIRELESS ENGINE MONITORING

Onboard calibration of diesel engines using wireless sensor networks and novel control approaches for emission reduction and fuel reduction in Small Marine Vessels

Description: One of the significant challenges in small and mid-size Marine Vessels is cutting the Fossil fuel use & air pollution generated by the marine diesel engines. This project develops an integrated energy monitoring system using an engine wireless sensor network (eWSN) and a propeller cartridge to enable torque & thrust data (with position/speed) readings and remote monitoring. We will use specialised and modern ultrasonic sensors to acquire the measurements in the harsh environment like ship's engine. Patented award-wining propeller cartridge, TorqueFlange®, will be employed for accurate torque & thrust readings using a network of sensors on different locations and proximities to the marine engine. An advanced sensor fusion technique is required to significantly reduce the probability of measurement error using signal processing and AI techniques. Moreover, an antenna array with directional radio links (beamforming) will be designed for the sensors to communicate in real-time with the control unit. Beamforming can provide narrow beams with significant gains, and directional and secure transmissions with high spectral efficiency. Link-budget study and ray-trace testing will be carried out to calculate the power loss in transmission and determine the best sensor location. The project is with the industrial partner, Duodrivetrain, the inventor of TorqueFlange.