Symbiosis of Electronics and Mechanical Engineering

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Interesting marriage is happening between Electronics and Mechanical Engineering evolving to encompass new conceptual approaches, leveraging the interdisciplinary nature of the two streams.

Current trends of Hyperloop transport, Self-driving cars, Industry 4.0, Soft Robotics are direct offshoots of deployment of new concepts that emanated from sustained R&D in mechanical engineering that catapulted modern factory to scale new frontiers.

Keywords: Hyperloop, Autonomous vehicles, Industry 4.0, Soft robotics, Beam energy propulsion, Smart materials, Nanoelctromechanical systems

I. INTRODUCTION

ENGINEERING is a very broad discipline. It involves scientific, mathematical, economical, social, and practical applications in its goal to find ways and create things that can help improve man's life and make his chores easier.

The discipline of mechanical engineering is a pervasive and deep one ranging from the smallest component to the complexity of a modern spacecraft. Being one of the oldest and broadest of the engineering disciplines, it involves design, production and operation of machinery from a tiny wrist watch to giant wind turbines.

Historically, Mechanical engineering emerged as a field during the Industrial Revolution of the 18th century. Today, it is an interdisciplinary field, comprising amalgamation of diverse scientific disciplines, leading to significant innovative developments in response to societal needs.

II. ADVENT OF HYPERLOOP

Today, transportation accounts for about 25 percent of the world's primary energy consumption and around 20 percent of the global CO_2 emissions!

A novel solution to these concerns is the concept of Hyperloop [1]. In the year 2018, Maharashtra decided to develop a high-speed line between Mumbai and Pune, which could possibly become the first hyperloop transportation system in the world. This hyperloop line was planned to cover 160 km distance in 35 minutes, a drastic reduction on current travel times of three and a half hours by car.

Figure 1. A smarter transport system that caters for social, economic and environmental sustainability is arguably one of the most critical prerequisites for creating pathways to more livable urban futures. *Hyperloop* will reinvent transportation to eliminate the barriers of distance and time.

Hyperloop technology was conceived by Elon Musk in 2013. The system would project pods at near-supersonic speeds through partially de-pressurized tubes. Proponents of the technology believe that it could be used to create a high-speed public transport alternative to trains and planes.

It involves building a near-perfect vacuum tunnel or tube, a railway track and a vehicle that floats above the track on magnetic levitation. A payload – passengers or cargo then accelerates through electric propulsion and picks up speed due to extremely low friction in vacuum. Hyperloops might one day become the fastest transit option with the lowest fuel (electricity) consumption rates.

Elsewhere, Virgin Hyperloop is planning a system to link Dubai and Abu Dhabi, while Elon Musk's infrastructure firm The Boring Company has permission to begin digging a tunnel in Washington DC to connect the city with New York. Another system has been proposed in Europe by Hardt Hyperloop, for which UNStudio has envisioned a series of modular stations, while a line to link Mexico City to Guadalajara in Mexico is also under development.

III. SELF-DRIVING CARS

Feverish R&D and trials are being conducted by auto makers in this emerging technology. Recent studies show inefficient transportation can reduce a city's productivity (measured in GDP) by up to 30 percent.

Self-driving cars are cars or trucks in which human drivers are never required to take control to safely operate the vehicle. Also known as autonomous or 'driverless' cars, they combine sensors and software to control, navigate, and drive the vehicle [2].
Various self-driving technologies have been developed by Google, Uber, Tesla, Nissan, and other major automakers, researchers and technology companies.

Figure 2. Autonomous vehicles leverage advances in mechanical and electronic engineering disciplines.

Self-driving systems create and maintain an internal map of their surroundings, based on a wide array of sensors, like radar. Uber's self-driving prototypes use sixty-four laser beams, along with other sensors, to construct their internal map; Google's prototypes have, at various stages, used lasers, radar, high-powered cameras and sonar.

Software then processes those inputs, plots a path, and sends instructions to the vehicle's "actuators," which control acceleration, braking and steering. Hard-coded rules, obstacle avoidance algorithms, predictive modeling, and "smart" object discrimination (*i.e.*, knowing the difference between a bicycle and a motorcycle) help the software follow traffic rules and navigate obstacles.

Humans are scared of technology taking over and don't want to give up control. However, 94% of accidents occur due to human error, with only 2% to vehicular malfunction, 2% to environmental factors and 2% to unknown causes. Thus, autonomous vehicles should not be feared, but rather celebrated as benefits are manifold. Self-driving technology could help mobilize individuals who are unable to drive themselves, such as the elderly or disabled.

Self-driving cars can be "connected", indicating whether they can communicate with other vehicles and/or infrastructure, such as next generation traffic lights. Thousands die in motor vehicle crashes every year. Self-driving vehicles could, hypothetically, reduce that number—software could prove to be less error-prone than humans—but cybersecurity is still a chief concern.

Just as humans are the leading cause of accidents, we are also the main reason for traffic. It just takes one person slamming brakes to cause a traffic jam. Cars would all work together as a unit, moving as one, getting rid of unnecessary brake slamming and traffic jams.

Such a car can drive itself without you even being in it. That means that your car can drop you off at the entrance of work or the grocery store or wherever you are going, and then park itself. You don't even have to be present. Further, because humans don't have to worry about getting in and out of the car in tight parking spaces, cars can park extremely close together to maximize the number of vehicles that can fit in one parking lot. With less traffic and more convenient parking, it will mean less stressful commute, allowing more free-time.

IV. INDUSTRY 4.0

Industry 4.0 or the industrial internet of things (IIoT) is the use of smart sensors and actuators to enhance manufacturing and industrial processes. It leverages the power of smart machines and real-time analytics to take advantage of the data that dumb machines have produced in industrial settings for years. The driving philosophy behind IIoT is that smart machines are not only better than humans at capturing and analyzing data in real time, they are better at communicating important information that can be used to drive business decisions faster and more accurately [3].

Smart Advanced Manufacturing and Rapid Transformation Hub (SAMARTH) - Udyog Bharat 4.0 is an Industry 4.0 initiative of Department of Heavy Industry, Government of India under its scheme on Enhancement of Competitiveness in Indian Capital Goods Sector. The initiative aims to raise awareness about Industry 4.0 among the Indian manufacturing industry through demonstration centers. Currently there are four centers which include Center for Industry 4.0 Lab Pune; IITD-AIA Foundation for Smart Manufacturing; 4.0 India at IISc Factory R & D platform; Smart Manufacturing Demo & Development Cell at CMTI.

India is now all geared up to catapult directly into the next revolution *i.e.* industry 4.0, where machines will be equipped with the ability to communicate.

Industry 4.0 (or The Fourth Industrial Revolution) is a level up, a modern insurgency that connects people, processes and machines. It is a combination of IIoT, cyber-physical systems

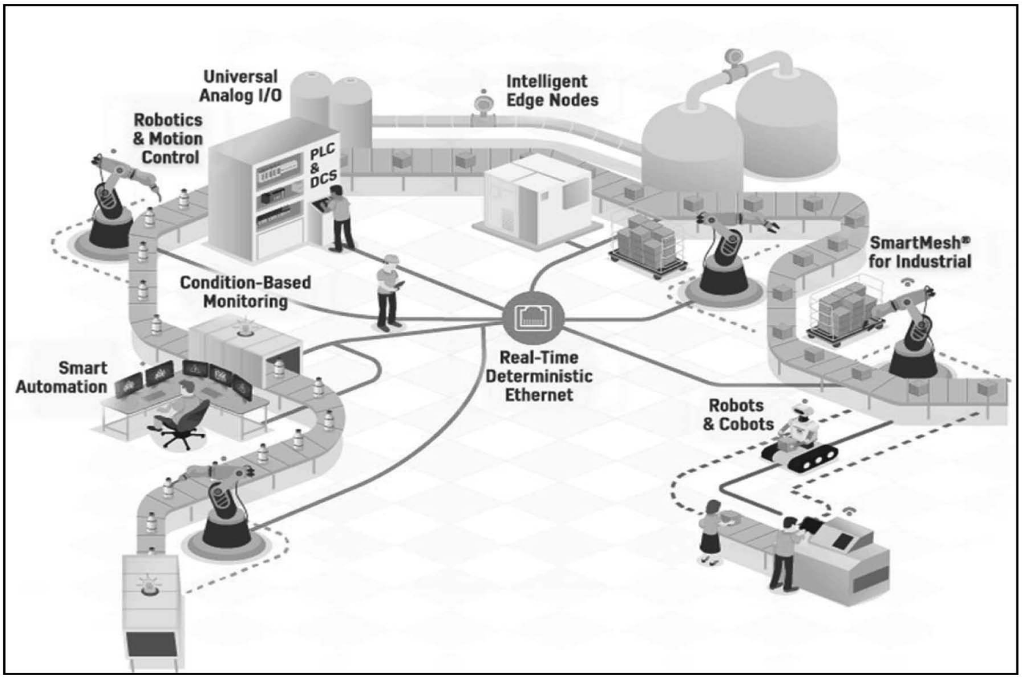

Figure 3. Internet of Things is at the heart of Industry 4.0.

and artificial intelligence, put together to ultimately make machines capable of making decisions with minimal human intervention.

Right now, there is a need to upskill talent within factories rather than replace them. The most important action is to invest in capability building and cultural change. Upskilling in areas of analytics and digital technologies will prepare the workforce for the changing environment.

Examples: In a real-world IIoT deployment of smart robotics, ABB, a power and robotics firm, is using connected sensors to monitor the maintenance needs of its robots to prompt repairs before parts break.

Airbus has launched what it calls "factory of the future," a digital manufacturing initiative to streamline operations and boost production. Airbus has integrated sensors into machines and tools on the shop floor and outfitted employees with wearable technology, industrial smart glasses, aimed at cutting down on errors and enhancing workplace safety.

Robotics manufacturer, Fanuc, is using sensors within its robotics, along with cloud-based data analytics, to predict the imminent failure of components in its robots. Doing so enables the plant manager to schedule maintenance at convenient times, reducing costs and averting potential downtime.

V. SOFT ROBOTICS

Research in soft matter engineering has introduced new approaches in robotics and wearable devices that can interface with the human body and adapt to unpredictable environments. Growing interest in soft robots comes from new possibilities offered by such systems to cope with problems that cannot be addressed by robots built from rigid bodies. Many innovative solutions have been developed in recent years to design soft components and systems. They all demonstrate how soft robotics development is closely dependent on advanced manufacturing processes.

Enthusiasm generated by soft robotics comes from the convergence of different scientific communities for the design

Figure 4. Soft robotics is a growing field in which engineers are building bendable machines with applications that range from laparoscopic surgery and prosthetics to disaster relief and space exploration.

of new machines. Born at the crossroads between chemistry, plastics engineering, and mechatronics, soft robots spread in a number of directions, leading computer scientists to work on design processes adapted to their non-conventional structural analysis, physicists and material engineers to innovate in sensing, power supply and information processing. The endless scientific and technological opportunities raised by the development of soft robotic systems has been such that a new scientific community has gathered in a very short time [4]. Soft robots have numerous applications, including aerospace, biomedical and surgical tools, assistive healthcare devices, tissue engineering etc. Embedding stimulus-responsive particles in polymers can enable actuation of composites for use in soft robotics and impart complex functions. The behavior of most soft robots is responsive because they are composed of elastomers that lack hysteresis in their mechanical response. Responsive materials respond to applied stimuli and return to their initial shape in the absence of stimuli. Soft robots that exhibit sequential and programmable responses are desirable for performing complex functions and in remote environments, such as *in vivo* applications or space. Recently, there has been notable progress in making soft robots reconfigurable, where arbitrary configurations can be locked in place, followed by unlocking and reconfiguration. It is also important to be able to program the configuration of a soft robot in the absence of stimuli.

Thermally activated shape memory polymers (SMPs) are related to elastomers but are stiff at room temperature and become soft and elastomeric when heated, which allows setting a temporary shape. Heating can trigger an SMP to recover its permanent shape.

VI. BEAM ENERGY PROPULSION

Another innovative advance in Mechanical engineering is “Beam-powered propulsion”, also known as directed energy propulsion -- a class of spacecraft propulsion that uses energy beamed to the spacecraft from a remote power plant to provide energy. The beam is typically either a microwave or a laser beam and it is either pulsed or continuous.

When a spacecraft is launched, the thrust comes from burning a chemical, such as rocket fuel. This fuel weighs down the spacecraft. It is an inefficient system when compared to using light or other electromagnetic radiation to accelerate objects [5].

Electromagnetic acceleration is only limited by the speed of light while chemical systems are limited to the energy of chemical processes. With beamed propulsion, one can leave the power-source stationary on the ground, and directly (or via a heat exchanger) heat propellant on the spacecraft with a maser or a laser beam from a fixed installation. This permits the spacecraft to leave its power-source at home, saving significant amounts of mass, greatly improving performance.

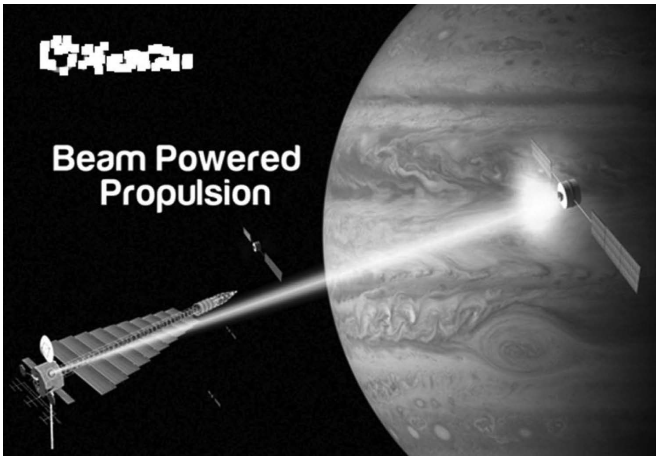

Figure 5. Beamed energy concept offers an alternative for an advanced propulsion system. Use of a remote power source reduces the weight of the propulsion system in flight and this provides significant payload gains.

Besides NASA, Indian Space Research Organisation (ISRO) is developing such a system at its LSPC (Liquid Propulsion Systems Centre). It involves developing an electric propulsion system (EPS) with a higher thrust level, which can reduce the dependence on chemical propellant. Benefits of this advancement include drastic reduction in time for space travel: one would reach Mars in days instead of months at present.

VII. NANOELECTROMECHANICAL SYSTEMS

Nanoelectromechanical systems are systems with characteristic dimensions of a few nanometers. By exploiting nanoscale effects, NEMSs present interesting and unique characteristics.

Sensors form the most essential components enabling advances in mechanical engineering. For instance, sensors built into aircraft let maintenance people know when repairs or more sophisticated inspections are required.

NEMS are a class of devices integrating electrical and mechanical functionality on the nanoscale. NEMS form the next logical miniaturization step from so-called microelectromechanical systems, or MEMS devices. NEMS typically integrate transistor-like nanoelectronics with mechanical actuators, pumps, or motors, and may thereby form physical, biological, and chemical sensors. Applications include accelerometers and sensors to detect chemical substances in the air.

NEMS combine smaller mass with higher surface-area-to- volume ratio suitable for applications regarding ultrasensitive sensors. A key application of NEMS is atomic force microscope tips. The increased sensitivity achieved by NEMS leads to smaller and more efficient sensors to detect stresses, vibrations, forces at the atomic level, and chemical signals. NEMS applications are envisaged in sensing, displays, portable power generation, energy harvesting, drug delivery and imaging [6].

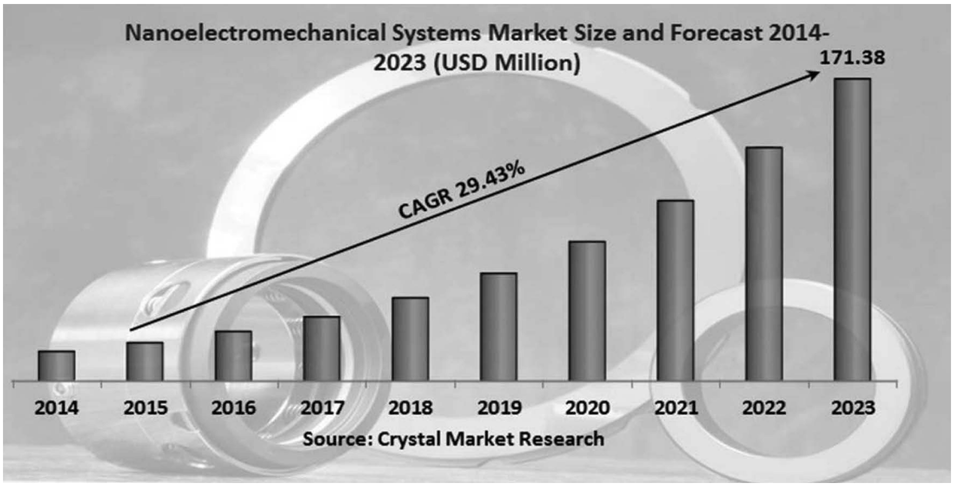

Figure 6. NEMS that confer mechanical and electrical functionalities on a nano scale are of rising interest as they offer a heap of benefits.

NEMS devices can have fundamental frequencies in the microwave range (~100 GH); mechanical quality factors in the tens of thousands (ultralow energy dissipation); active mass in the femtogram range; force sensitivity at the atto-newton level; mass sensitivity up to atto-gram levels; heat capacities far below a "yoctocalorie"; power consumption in the order of 10 aw; and extreme high integration level, approaching 10^{12} elements per cm^2 . All these distinguishing properties of NEMS devices pave the way to applications such as force sensors, chemical sensors, biological sensors, and ultrahigh frequency resonators.

Due to significant advances in growth, manipulation, knowledge of electrical and mechanical properties, carbon nanotubes have become the most promising building blocks for the next generation of NEMS. As a result of the recent progress in fabricating large-area graphene sheets, graphene-based mechanical devices have become vastly easier to manufacture and now show even greater promise for a range of applications.

VIII. SMART MATERIALS

Smart materials are beginning to play an important role in engineering designs. They are being developed via collaborative efforts of engineers with specialization in mechanical, electronic and chemical engineering. Smart materials are the materials that have one or more properties that can be significantly changed in a controlled style such as stress, temperature, moisture, pH, electric or magnetic fields.

Composite materials, called Smart materials are generally used for buildings, bridges, and structures such as boat hulls, swimming pool panels, racing car bodies, shower stalls, bathtubs, storage tanks, imitation granite and cultured marble sinks and countertops. The most advanced examples perform routinely on spacecraft and aircraft in demanding environments.

Work on smart composites focusses on incorporation of a functional material or device in a matrix material for enhancing the smartness or durability, while that on smart materials has studied materials (*e.g.* piezoelectric) used for making relevant devices.

Modern products increasingly use them, *e.g.* shirts that change color with changes in temperature. With benefits for aerospace, medical, textile, construction, and electronics industries, smart materials improve efficiency and save resources by responding to corrosion, pH changes, water content, temperature, mechanical forces, and much more.

Intrinsically smart structural composites are multifunctional structural materials which can perform functions such as sensing strain, stress, damage or temperature; thermoelectric energy generation; EMI shielding; and vibration reduction.

The advances in modern engineering are determined, to a large extent, by the development and application of advanced composite materials. Today's composites are light-weight, corrosion-resistant, and very strong. Composite materials are made of at least two different constituent materials, for example fibers and resin matrix.

Carbon nanotube diameter is about 5 nanometers, and yet the extraordinary mechanical properties of carbon nanotubes qualify them as the ultimate fibers ever made. In the last few years, carbon nanotube reinforced composite materials have shown considerable developments. It is estimated that global market for nano-composites will expand with an annual growth rate of 24% from 2014 to 2020.

These innovative materials are making revolutionary changes in modern engineering. They can be described as adaptive structures, which incorporate sensors and actuators. Smart structures can assess their own state and perform self-repair and self-adjustment as conditions change and thereby enhance their functionality and survivability. The ultimate objective of smart materials is to replicate biological functions in man-made structural elements.

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- Big Data: Challenges and opportunities (Feb 2017)
- Smart Cities (April 2017)
- Lure of ISM Band (July 2017)
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