BRAINSTORMING MEETING BY CSIR-HRDC

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Report on

Brainstorming

on

STRUCTURAL HEALTH MONITORING OF BUILT-UP AND INDUSTRIAL INFRASTRUCTURE

July 31, 2020

CSIR-Structural Engineering Research Centre (CSIR-SERC)
Chennai

CSIR-Human Resource Development Centre (CSIR-HRDC)
Ghaziabad

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Report on

Brainstorming on

STRUCTURAL HEALTH MONITORING OF BUILT-UP AND INDUSTRIAL INFRASTRUCTURE

Date of Event: Friday, July 31, 2020 Time: 10:00 am to 21.00 pm.
Size of group: About 200 Via : MS Teams Platform

Preamble:

CSIR has initiated organizing brainstorming sessions on emerging areas of science and technology involving the national and international experts so as to develop futuristic research agenda to become a global leader in identified areas. The first brainstorming under this initiative was organized jointly by CSIR-Structural Engineering Research Centre (CSIR-SERC), Chennai and CSIR-Human Resource Development Centre (CSIR-HRDC), Ghaziabad on ***Structural Health Monitoring of Built-Up and Industrial Infrastructure*** on 31 July 2020 through MS Teams platform. It was a historical pan-CSIR event, where the SHM experts from around the world actively deliberated.

Aggressive R&D efforts are currently underway across the globe on developing robust SHM technologies. In this context, it is imperative that CSIR timely exploits its multi-disciplinary capabilities for a globally competitive futuristic technology development initiative on Structural Health Monitoring of Built-up and Industrial Infrastructure. The goal of this initiative will be to become a global leader in this area and make indigenous state-of-the art technologies available for the country's infrastructure health monitoring at reduced cost, and prevent loss of lives and properties. The brainstorming was conceived and detailed to bring together the experts from academia and industry, and the stakeholders to set the path for the futuristic goals.

The brainstorming has provided a unique space for exchange and discussion among 200 participants representing research institutions, academia, private and public sectors from India and around the world. The programme was charted out to cover the activities relating to CSIR laboratories and the industry who are working in the area of SHM. The brainstorming session was divided in three segments, namely (i) Understanding the need (contributed by the industry and stakeholders), (ii) Setting the goal (contributed by the experts), (iii) Setting the path (through panel discussions). The last segment was held under three verticals, namely, Vertical 1: Built-up infrastructure, Vertical 2: Aircraft structures, and Vertical 3: Industrial machineries, process vessels and equipment.

The programme started at 10.00 am and ended at 09.00 pm on 31 July 2020 with a mid-break of 3.30 hr to accommodate different time zones of the countries attended by the foreign experts. Labs participated in the programme are CSIR-SERC, CSIR-NAL, CSIR-NML, CSIR-CRRI, CSIR-CBRI, CSIR-CMERI, CSIR-CGCRI, CSIR-AMPRI, CSIR-CEERI, CSIR-CECRI, CSIR-CSIO, CSIR-CIMFR, CSIR- 4PI.

The following are the experts involved in the brainstorming session.

International experts:

1. Prof. Fu-Kuo Chang, Department of Aeronautics and Astronautics, Stanford University, USA
2. Prof. Tribikram Kundu, Civil & Architectural Engineering & Mechanics Department, Aerospace & Mechanical Engineering Department, Materials Science & Engineering Department, University of Arizona, USA
3. Prof. Dr.-Ing. Christian Boller, Chair for Non-Destructive testing and Quality Assurance (LZfPQ), Universitaet Saarland, Germany
4. Prof. Victor Giurgiutiu, University of South Carolina, USA
5. Dr. Putcha Sastry, Smart Structures, Florida, USA

Academic experts from India:

1. Prof. S. Gopalakrishnan, Department of Aerospace Engineering, Indian Institute of Science, Bangalore
2. Prof. Suresh Bhalla, Smart Structures and Dynamics Laboratory, IIT Delhi
3. Prof. Ananth Ramaswamy, Department of Civil Engineering, Indian Institute of Science, Bangalore
4. Prof. D. Roy Mahapatra, Indian Institute of Science, Bangalore

Experts from Industry:

1. Dr. V. Govindaraj, Head, R&D Cell, Residential buildings, L&T Construction, Manapakkam, Chennai, PIN : 600089
2. Dr. Arun Pundi Ramu, M/s Honeywell International Inc, Bangalore
3. Dr. Arko Dasgupta, M/s Mageba, Kolkata
4. Dr. Samuel Varghese, M/s SFO Technologies, Cochin
5. Mr. R.S. Maurya, NTPC, New Delhi

Key experts from CSIR:

1. Prof. Santosh Kapuria, Director, CSIR-Structural Engineering Research Centre (CSIR-SERC), Chennai
2. Shri Jitendra J Jadhav, Director, CSIR-National Aerospace Laboratories (CSIR-NAL), Bangalore
3. Dr. Indranil Chattoraj, Director, CSIR-National Metallurgical Laboratory (CSIR-NML), Jamshedpur
4. Dr. N. Gopalakrishnan, Director, CSIR-Central Building Research Institute (CSIR-CBRI), Roorkee
5. Dr. Pradeep Kumar Singh, Director, CSIR-Central Institute of Mining and Fuel Research (CSIR-CIMFR), Dhanbad
6. Prof. S. Anantha Ramakrishna, Director, CSIR-Central Scientific Instruments Organization (CSIR-CSIO), Chandigarh

Welcome by Dr. R.K. Sinha, Head, CSIR-HRDC

The inaugural session started with welcome remarks by Dr. R. K. Sinha, Head, CSIR-HRDC. He welcomed Dr. Shekhar C. Mande, Secretary, Department of Scientific and Industrial Research and Director General, Council of Scientific and Industrial Research, Directors of various CSIR laboratories, experts from academia and industry both from India and abroad, to the Brainstorming on Structural Health Monitoring.

Dr. Sinha, in his remarks, said that since its genesis on 1942, CSIR has provided cutting edge inventions and technologies to the country and has always risen to the occasion when the country was facing emergencies such as the latest one - the COVID-19 pandemic. He also emphasized the contributions of CSIR to fight against COVID-19. He further pointed out that CSIR has proved its mettle during the current national emergency by augmenting testing facilities in 15 CSIR labs across India. CSIR is also working very closely with the industry for developing vaccines.

He informed the participants that this brainstorming session is the first one in the series of 12, one topic per month, being launched by CSIR. It is the outcome of the recommendations given by CSIR Society and also as per the vision of the Hon'ble Prime Minister of India to encourage futuristic research. Referring to the topic 'SHM', he mentioned that CSIR has developed expertise in area of civil infrastructure, failure analysis of turbines, aircraft, vital infrastructure, nuclear power plants, hospitals, etc. He expressed that CSIR always thinks ahead of time in terms of providing solutions to society through its S&T interventions.

Inaugural Remarks: Prof. Santosh Kapuria, Director, CSIR-SERC

Prof. Santosh Kapuria, Director, CSIR-SERC, and CIE theme Director, in his inaugural address, welcomed all the participants and mentioned that this is "a historic pan CSIR brain-storming event for developing futuristic agenda". He thanked DG, CSIR, Dr. Mande for giving him the opportunity to conduct this kind of brainstorming on 'SHM' which can help India to become leader in the domain. Prof Kapuria expressed his deep satisfaction as the internationally renowned researchers and academicians in this important area, besides the partners from industry and stakeholders from different parts of the world have gathered to mark this occasion with a common goal of keeping infrastructure safe. He expressed his confidence that a desired road map/recommendations on the SHM for various infrastructure sectors will be brought out, as an outcome of the brainstorming. He also briefly outlined the various sessions that were planned for the day.

Keynote Address: Dr Shekhar C. Mande, Secretary, DSIR and Director General, CSIR

Dr. Shekhar C Mande, Director General, CSIR, and Secretary, DSIR, delivered the keynote address. In his address, he welcomed all the participants and briefed on the

genesis and contribution of CSIR to the country. He pointed out that CSIR is the oldest public funded S&T organization which was established before independence and is also the mother of all scientific institutions in the country. He said that the 37 CSIR laboratories across India are working on almost all areas of S&T and that three major civil engineering laboratories are CSIR-SERC, CSIR-CBRI, and CSIR-CRRI. He briefed on the governing body of CSIR and CSIR Society meeting, stating that organizing the high-level and deep brainstorming sessions were suggested by none other than the Prime Minister of India, Shri Narendra Modi who is the Chairman of the CSIR society. He also informed that the vice president of the society is Hon'ble Minister of Science & Technology Dr Harsh Vardhan. Dr Mande said that taking forward the CSIR Society's suggestions, the first brainstorming session is being organized on a very significant area of SHM and such sessions can play a great role in the development of frontline technologies in India and can also prepare us to collectively work for the future. He complimented Prof. Kapuria for being able to bring together a phenomenal panel of experts from across the world for this brainstorming in a short time.

Brainstorming of SHM : Presentations and Views by the Experts

***Setting the context* by Prof. Santosh Kapuria, Director, CSIR-SERC, Chennai :**

Prof. Santosh Kapuria, made a brief presentation on '*Brainstorming of SHM of Built-up and Industrial Infrastructure'* for setting the context of the brain-storming. He pointed out that in spite of extremely rigorous and stringent time-based maintenance regimes and the most advanced analysis based design principles followed in some critical structures such as the aircraft, industrial structures, static equipment and process vessels, nuclear reactors, and space shuttles, catastrophic failures continue to take place claiming invaluable lives and critical engineering assets. Also, such failures bring to evidence a serious gap in today's science and technology capabilities. Conventional non-destructive evaluation (NDE) based maintenance can do little when flaws are induced and become critical between successive maintenance schedules.

While outlining the schematic processes involved in the SHM, Prof. Kapuria underlined that the goal of SHM is the real time detection of damages at an early stage of their growth. It is essentially achieved by combining the conventional NDE with built-in actuators and sensors, and appropriate domain models and data analytics for feature extraction from the sensor signals for detecting, localizing and characterizing the damage. He then briefly described the research being carried out at various CSIR laboratories in the area of SHM. His presentation highlighted important aspects in the field of SHM, as given below:

- SHM prevents catastrophic failure, reduces downtime, increases in operating life, which results in reduction in life cycle cost.

- SHM can ensure safe running of aging infrastructure such as old bridges and refineries that are 70-100 years old. SHM can also ensure safe operation of cross-country pipelines (which run thousands of kilometres) without the need of operational shutdown.
- Classification of SHM systems, hierarchical structure of SHM, diagnosis, prognosis, schematic of SHM process, strategies of SHM, baseline free SHM, future trends and challenges – such as stretchable sensors, vision based sensing, optimal sensor placement, sensor fault detection, etc.
- Leads from recent R&D through CSIR Mission Mode project – i) Technologies for robust SHM of critical infrastructure and conservation, ii) IOT-Cloud enabled integrated online SHM framework development architecture, iii) identification of the breathing crack type damage in RC bridges through dynamic data fusion and machine learning tech for SHM, iv) Refined baseline-free damage identification in thin-walled structures using lamb wave propagation, v) distributed fibres optic sensors for SHM applications, and vi) use of piezo-patch as an innovative technique for active-passive sensing
- Proposed way forward – indigenous development of advanced sensors, optimized sensor placement scheme, data driven models, etc.

Finally, Prof. Kapuria outlined the focus of the brainstorming, namely, i) understanding the needs of the industry, ii) setting the goals in line with the vision 2025 for India, iii) charting the path with recommendations

Expert Views : by Prof. Tribikram Kundu, University of Arizona, USA

Prof. Tribikram Kundu made a presentation on '*Current research achievements and challenges on linear and nonlinear ultrasonic techniques for SHM'*. He emphasized on the need and importance of research collaborations, both at domestic and international level for exchange of new ideas/innovative solutions to address the challenging problems. He discussed on the steps of SHM for large structures by presenting his research work, citing examples appropriately, through various collaborative projects as highlighted below :

- Acoustic source localization (ASL) in anisotropic structures without knowing its properties – in collaboration with University of Tokyo
- ASL in heterogeneous structures – in collaboration with Jilin University, China
- Wave front shape based ASL analysis - in collaboration with AGH University, Krakow, Poland
- Composite plate inspection with AFR laboratory, USA
- Nonlinear ultrasonic techniques with Valencia Polytech., Spain and KAIST, South Korea
- Composite damage inspection – linear and nonlinear technology with University of Naples, Italy

- Linear and nonlinear techniques for monitoring concrete curing with CSIR-SERC, India
- Reinforced structure inspection with Polytechnic University of Bari, Italy
- Biological cell characterization with Goethe University, Germany
- DPSM modeling with ENS Cachan, France

For a query on whether these technologies developed are being applied in structures on real time, he replied that some of these technologies are being applied and there is a lot of interest in the area of nonlinear ultrasonic techniques.

Expert Views : by Prof. Fu-Kuo Chang, Stanford University, USA

Prof. Kundu's presentation was followed by the presentation on '*Structural Health Monitoring for IIOT*' by Prof. Chang. He discussed on the transition from industry 1.0 to industry 3.0 which encompasses automation, computers and electronics. Further, he emphasized that industry 4.0 or Industrial Internet of Things (IIOT) which has evolved around the themes of cyber physical systems, internet of things, networks leading to the concept of digital cities, needs the massive amount of data (big data) in real-time to be "intelligent and autonomous". Further he pointed out that SHM is the backbone platform of IIOT and the value added to IIOT is the ability to sense and collect data, analyse and communicate the information through NextGen sensor network. He also briefed on i) IOT based SHM system for global mining machine (IOT-based remote SHM solutions), ii) iROLL system – real time smart roller monitoring system for ensuring the integrity of paper manufacturing rollers (as an example) and iii) SHM system for 737 aircraft where SMART layer sensors are connected to a data analysis software platform for performing functions such as diagnostic data collection, managing data and processing data to provide quantified damage results. He also mentioned on aircraft health management and the need for world-wide SHM standardization. Prof. Chang outlined the world-wide SHM standardization effort since 2016 and cited a military standard MIL STD 1530D which carries sections on SHM as a technique, structural risk analysis, etc. He concluded his presentation by emphasizing on the significance of international collaborations.

Remarks by Prof. Kapuria

Prof. Kapuria summarized that the idea of IIOT and SHM are the backbone for monitoring various structures. Further, he expressed that standardization and collaborations are the key to future research in SHM. He also assured the participants that CSIR will work towards achieving it and will set benchmarks for others to follow.

Brainstorming Session I - Understanding the need: Input from Industry

Session 1 of brainstorming started after a short break, focussed on the inputs from industry in which experts from industry shared their experiences and the challenges faced by them.

Industry views : by Dr. V. Govindaraj, L & T, Chennai

Dr Govindaraj presented a brief outline on the process of implementing a damage detection and characterization strategy to engineering structures and mentioned that SHM can be done broadly in three different levels (i.e., material, element, system). Further, he illustrated at material level by taking example of corrosion, sulphate attack, temperature effects etc. in concrete. He then elaborated that, for SHM at the structural element level, strength deterioration, deflection, strain measurements, axial deformation, wind pressure measurement, strength monitoring, strength deterioration, etc are considered as parameters. Dr Govindaraj also pointed out the issues like installation and performance monitoring of viscous dampers, friction plate dampers, monitoring of bearings in bridge supports etc. are required to be addressed through proper SHM strategy in element level. Moving on to the system level, he stated that parameters such as settlement of foundation, drift due to wind, acceleration under wind load, etc. play a key role in monitoring the structures. His presentation concluded with the highlighting of L&T's adoption of SHM in various projects and that they were seeking solutions to some of the problems faced by them. Responding to Dr. Govindaraj, Prof. Kapuria informed that some solutions that L&T is looking for are already available with CSIR-SERC and that many others can also be provided by working in collaboration.

Industry views : by Dr. P.R. Arun, Honeywell, USA / Bangalore

The talk by Dr. Arun from Honeywell, highlighted on the need for development of safety and productivity solutions and for specializing in sensor based technologies. He also opined that research institutions and industry should work more closely to develop necessary technologies for the people and country. He also mentioned the on-going discussion with CSIR-SERC on jointly developing the SHM technologies for which NDA is being prepared.

Industry views : by Mr Arko Dasgupta, M/s Mageba, Kolkata

Mr. Arko Dasgupta from Mageba, in his presentation on '*ROBO Control Monitoring System*' brought out the following:

- Importance of SHM to prevent collapses and casualties across India and at the international level with few examples and the limitations of manual monitoring
- A systematic flowchart for implementation of SHM in a typical bridge, stating that the basic flowchart remains the same for most of the monitoring projects
- Main objective of typical bridge SHM, which ensures transfer of data to the system uninterrupted and accurately
- Outcome of SHM – intelligent structures, measurement of environmental parameters and structural response, etc.
- Products by Mageba such as ROBO® SMART for expansion joints and bearings that are used for instrumentation of structures and explained on how they work with respect to data acquisition and transmission
- The need for use of special high grade industrial computers, digital cabling, protected data transmission cables, etc.
- Examples of measurement of rebar strain, natural frequencies, various outputs of the Mageba software via the web user interface
- Illustrated examples of monitoring work done by mageba on the Hanging bridge of Kota, WEH Metro bridge, Mumbai, Barddhaman ROB, West Bengal, Ultadanga flyover, Kolkata, Bogibeel bridge, Assam, etc.

Responding to the presentation, Dr. Jitendra Kumar Goyal of CRRI pointed out that many structures are not monitored after instrumentation and it is important to have a robust long-term mechanism for follow-up action. Prof. Kapuria in his remarks said that the main challenge in SHM is the interpretation of the huge amount of measured data through feature extraction algorithms for identifying damage, and CSIR-SERC is ready to work with Mageba for integration of their sensor products with data interpretation software.

Industry views : by Dr Samuel Varghese, SFO Technologies, Cochin

Mr. Dasgupta's presentation was followed by a presentation by Dr. Samuel Varghese of SFO Technologies, Cochin. In his presentation, he briefed on the expertise of SFO Technologies and the products developed by them. He said that the strength of SFO Technologies lies in the areas of fibre optics, FBG based sensing, distributed fiber sensing systems, direct buried cable access simulation, monitoring and alarm management, packaging of sensors, interrogators, innovative photonics solutions, optical sensor systems, optronics manufacturing, opto-electronics manufacturing, testing assemblies, etc. and that some of the real time issues being faced were mounting of FBG sensors on to the structure and packaging, for which his company is open for collaborations.

Industry views : by Mr R.S. Maurya, National Thermal Power Corporation,

The final presentation of Session 1 was made by Mr. R.S. Maurya of National Thermal Power Corporation (NTPC). In his presentation, Mr. Maurya, briefed on NTPC as an organization and the collaborative projects undertaken with various academic and research institutions. Further, he cited the problems faced in inspection and managing of high-rise civil and steel structures such as boilers, chimney, conveyor belts, equipment foundation, C.W. duct, long distance pipelines, under water pumps and reservoirs, turbine structures, steel structures in coastal areas and cooling towers, etc. It was mentioned that drone inspection, visual inspection, vibration analysis, re-casting of foundation, robotic system for detection of internal defects, cleaning, coating, etc were also highlighted are being adopted by NTPC. He concluded his presentation by stating that NTPC is looking for solutions from national and international bodies for integrity checking of civil structures and equipment foundation, estimation of crack propagation, welding integrity and for the protection of civil and steel structures in the coastal areas.

Brainstorming Session II : Setting the goal - Input from academic experts

Expert Views : by Prof. S. Gopalakrishnan, Indian Institute of Science, Bangalore

The Session II of brainstorming began in the evening with the presentation on '*Non contact sensing for SHM in Aerospace Structures'*, by Prof. S Gopalakrishnan, IISc, Bangalore. In his presentation, he briefly introduced the area of SHM and its targeted applications such as civil and military aircraft structures, rotary-wing aircraft structures, space craft, rotating machinery, etc. With reference to aerospace engineering, he discussed on the anticipated benefits such as prognostic capabilities and maintenance of SHM. Further, he discussed about online and offline SHM for aerospace structures, sensing technologies, etc. He pointed out that, there are lot of advancements in offline SHM and how it can greatly help in reduction of aircraft maintenance costs. He also briefed on:

- Scanning laser Doppler vibrometer – an enabling technology for noncontact off-line structural health monitoring and its highlights
- Guided waves vs Ultrasonics
- NPMASS initiative – under which several SHM technologies were developed
- Results of the first effort by IISc with industry for creating an SHM centric software
- Field testing of F15 and F16 aircraft
- Air coupled ultrasonic system for SHM

- Robotic SHM inspection where the developed approach is suitable for automation and local inspections on large areas can be done easily in a hangar setting

Summarizing his presentation, Prof. Gopalakrishnan reiterated that laser vibrometry can be easily adopted for condition based maintenance of aircraft rather than scheduled maintenance. In addition, it has a very powerful imaging tool, which can be used for damage detection. It is a very good candidate for offline SHM. Though it is more suited for aerospace applications, but can be migrated to other disciplines.

Responding to the query by Dr N. Gopalakrishnan, Director, CBRI, regarding insurance and standards, Prof. S. Gopalakrishnan replied that as such there are no standards for SHM and called upon CSIR-SERC to take the lead in developing standards and said that unless there are standards, insurance will not be possible.

Expert Views : by Prof. Suresh Bhalla, IIT Delhi.

The second lecture of Session II was given by Prof. Suresh Bhalla, IIT Delhi, on the topic '*SHM Academic perspective: way forward for India and world*'. In his talk, he spoke on the Technology Readiness Levels (TRL) and urged the researchers to pursue till TRL 9, so as to bring the new ideas to market. Looking at the futuristic opportunities, Prof. Bhalla expressed his views on technology start-ups, requirements of continuing education and manpower training, need for development of low cost sensors, integrating SHM and energy harvesting, Make in India, etc. He opined that the success drivers in SHM were techniques that are not heavily dependent on modelling and are less dependent on baseline data, reusable, rugged and long-life sensors, techniques that are cloud and IOT enabled, self powered and those that can be integrated with AI. He illustrated the functioning of a low-cost sensor, electro-mechanical impedance (EMI) technique for fatigue life assessment, empirical model for residual life determination from stiffness loss, etc. Highlighting the development of a new Concrete Vibration Sensor (CVS) which is a ready to use PZT-cement composite sensor, he explained its use in damage severity assessment. Prof. Bhalla explained the use of Concrete Vibration Energy Harvester (CVEH) as against the CVS and also showed how RC slabs under blast loading were monitored using CVS. He showcased the different prototypes of advanced reusable piezo sensors. Drawing attention to the need for futuristic energy harvesting for requirements ranging from watches to laptops, he presented the work done by the Virtual Smart Structures and Dynamics Laboratory of the Department of Civil Engineering IIT Delhi (http://www/vlab.co.in / http://ssdl.iitd.ac.in/vssdl) and India's future roadmap which emphasized key areas such as the need for SHM trained engineers, industry-academic joint research, ecosystem for academicians, start-ups and industry and a policy to initial inclusion of codes of practice.

Expert Views : by Dr -Ing. Christian Boller, Universitaet Saarland, Germany

The next presentation '*Is Damage Affordable*?' was by Dr –Ing.Christian Boller, in which he brought out the principle of damage tolerance – with and without inspection of the structure in relation to parameters such as light weight design, safe life, etc. He opined that (i) safe life designed structures have to be removed when achieving the life of the weakest structure, (ii) fatigue life of structures can scatter by a factor of two or more, (iii) monitoring and inspection can lead to longer operational life or lighter weight of structures. Further, Prof. Boller explained the damage tolerant design principle with reference to non-destructive testing and design. He went on to describe a structure's life cycle process chain assessment, a requirement of simulation model for civil engineering, which involved factors such as loads, geometry (CAD), loading(FE), damage, NDT inspection, SHM and validation. In view of saving public money, he emphasized on adding value through monitoring of structures which can be used for determining the residual life and also the maintenance cost through various examples. Potential examples for such monitoring include civil structures such as road bridges, railway bridges, tunnels, wind power plants, buildings, etc. On the steps to be taken in future, he enumerated on the following points:

- Assessing engineering structures with respect to their damage tolerance potential
- Developing a customized damage tolerance concept for the engineering structures
- The concept of damage tolerance (hardware and software) to be implemented in the structure
- Managing the respective damage tolerance concept with respect to data generation, storage and processing

Expert Views : by Prof. Debiprosad Roy Mahapatra, IISc, Bangalore

The presentation by Prof. Debiprosad Roy Mahapatra, IISc, was made on '*Shaping the problem statement of SHM – the cantilever beam problem'*. He presented the cantilever beam problem as an example due to parameters such as assumed load, known configuration, known material properties, etc. He enumerated the example based on paradigm levels 0-3 for a structural system (described as Level 0 for existing practice, i.e., analysis, design, testing, diagnosing, etc., Level 1 for enhancing understanding of environment and usage, Level 2 for high-level awareness based management, repair and level 3 for enhancing understanding of how the future structures should be designed and maintained). He pointed out the need for looking at a broader picture by giving due consideration for advancement of life and environment and at the same time looking at the social and economic aspirations of different entities and finally creating local support system with simple

technologies & tools. He emphasized that there is a need for education & training which is totally missing at present and this should be addressed and requested CSIR to consider them in earnest. He elaborated on the creation of monitoring bodies for various developmental verticals such as process flow and evaluation, R&D of SHM components, field-level engineering innovation and implementation pipeline, developing logistics capability, developing support system, business ecosystem, policy and planning, etc.

Responding to the presentation, Prof. Boller emphasized the need to assess engineering structures with respect to damage tolerance potential, develop customized damage tolerance concept for the engineering structures, get damage tolerance concept realized in hardware and software and to manage the respective damage tolerance concept with respect to data generation, storage and processing.

Expert Views : by Prof. Ananth Ramaswamy, IISc, Bangalore

The next presentation was by Prof. Ananth Ramaswamy, IISc, in which he spoke on:

- Tools for condition assessment of existing structures
- Tools for assessing available safety
- Assessment of structural concrete safety against thermal loads
- Developments in repair/retrofit
- Condition assessment of railway bridges in India's west coast

He supported his ideas with detailed examples of various collaborative studies undertaken to assess deflection and stress levels of bridges using sensors such as acoustic emission sensors. The studies carried out in the field and comparison with FEM predictions were also presented.

Expert Views : by Prof. Victor Giurgiutiu, University of South Carolina, USA

The final presentation of Session II was by Prof. Victor Giurgiutiu of University of South Carolina. In his talk, he discussed on some of his recent research works on active and passive SHM, SHM using guided waves, new numerical techniques, etc. Prof. Giurgiutiu also explained about PWAS (Piezoelectric Wafers Active Sensor) and their role in active and passive SHM due to low cost and ready availability. He enumerated the various techniques for structural health monitoring as follows:

- Active guided wave SHM of composites
- Damped guided wave prediction in composite plates
- Detection of multilayer delamination
- Passive SHM via acoustic emissions

He shared his new discovery on the presence of acoustic emission signals even in the cases when crack is not propagating which can open up a new area of research on acoustic emission technique. He also called upon the participants to explore their LAMSS website for updates and information of his group's work.

Brainstorming – Session III : Setting the path - Panel discussions

Session III – Panel Discussions were arranged for three verticals sequentially.

Setting the path for **Vertical 1**: **Built up infrastructure**

- *Moderator*: Prof. Santosh Kapuria, Director, CSIR-SERC
- *Experts*: Dr. Arun Pundi Ramu, Honeywell International Inc, Bangalore
  Dr -Ing. Christian Boller, Universitaet Saarland, Germany and Prof. Ananth Ramaswamy, Indian Institute of Science, Bangalore

Views/Comments by Dr. Arun : Factors driving towards large scale adoption of SHM solutions are residual life enhancement and cost of safety. In order to bring down the cost, there is a need to bring the subject matter expertise of the product that is to be standardised as was strongly brought out by Dr –Ing. Boller. SHM in its entirety is driven by safety and the typically the two main categories that call for attention for SHM are the variety, scale and volume of bridges, civil structures, tunnels, etc and also on old structures (as there is no information and data on how they were built and how they are being monitored). Thus, there is a need for good data for bringing the cost down resulting in a positive drive towards adoption of SHM. More than infrastructure improvement, there is an immediate need for change in outlook towards SHM adoption and probably a mandate should be set by the government. Next the question of ownership of data and funding of structures, it is required to look into collecting, collating and assimilating of data on a single platform to facilitating SHM research by way of funding from various agencies.

Views/Comments by Dr -Ing. Boller's : Prof. Boller while commenting on the participation of industries that manage and monitor large structures, emphasized on the need to learn case by case and for the continued existence of the current participating forum. He stated that as experts from various fields they could guide those who seek to implement SHM. He also pointed out that there is no data for old structures and that data can be collected and built to form a sort of data "backbone" for old structures for smart maintenance. Prof. Boller commented on the importance of inputs by way of techniques from related fields such areas of acoustics guided wave, electromagnetics, optics, environmental sensing, corrosion sensing for

monitoring old structures. These can be put to good use by “some creative thinking or lateral thinking.”

Views/Comments by Prof. Ramaswamy : Prof. Ramaswamy expressed the need for big data handling, data driven processes, IOT, hybrid technologies, etc. Since SHM involves a lot of data handling and data driven processes, he said that physics must be a corrective factor in the data driven approaches that lead to online health monitoring. Monitoring of structures online and with wireless technologies requires high computing technology and the cost factors need to be addressed. Further, he suggested that, there is a need for a game changing technology such as satellite based monitoring on a large number of infrastructures, an idea which is too far in the future. Hence, for the near future he suggested the use of hybrid technology and IOT combined with lab measurements, field measurements and modelling. Finally, he emphasized on the need identify the structure and structural elements that need to be monitored to portfolio the investments.

The discussion was opened to the forum and the responses are as given below.

Dr. G.K. Sahu of CSIR-CRRI drew attention to the work undertaken for instrumentation and monitoring of 12 bridges in Goa, Mumbai, Varanasi, etc starting as far back as in 1988-89. He suggested monitoring the already instrumented bridges as they are mostly not followed up properly after instrumentation. Further, he informed that 3 cable stayed bridges were to be built in India where instrumentation for monitoring has been proposed.

Prof. S. Gopalakrishnan, IISC, put forth his observation that the design philosophy of civil engineers needs to be changed, in order to move from conventional techniques to damage tolerance techniques, if not already done. Also, he emphasised on the need to bring out the standards for SHM of civil infrastructures such as those already available for steel, concrete, etc. He also opined that, once standards have been developed for SHM of civil engineering, the same can be spread for areas such as aerospace and that CSIR-SERC is well placed to carry out this work of bringing out standards for implementing SHM concepts right from the design phase itself.

Dr. Satish Kumar, CSIR-CSIO, observed that the programme was very informative and well taken. He drew attention to the fact that, railway bridges and gas pipelines are technology dependent for identifying cracks and said that GAIL is very much interested in such technology. He opined that there is a need to know more on the IOT protocols, data formats, different kinds of sensors, cost factors, communication methods, etc. for the formation of the built-up vertical that is currently being discussed. From instrumentation point of view, he said that they would fully cooperate for any participative activity.

In reply to a question from Dr. Amitha, CSIR-NAL, Dr -Ing. Boller informed that scientists at the Australian Defence Research Institute, Melbourne have done some studies regarding corrosion sensors. Further, he pointed out that data gathered from monitoring of bridges for more than 30 years as stated by Dr. G.K. Sahu is very valuable and recommended that these cases should be presented in an orderly and meaningful manner in future meetings. He also said that since civil engineering is a highly safety driven field, the concept of damage tolerance has indirectly been introduced through partial safety factors. He emphasized on the urgent need to apply SHM to existing structures.

Dr. S.S. Gaharwar, CRRI-CRRI, observed that in the current Indian scenario, though there is a lot of focus on maintenance of structures and there is an urgent need to introduce SHM from the initial stages of construction especially for design features whose long term performance is not known. Adding to this, Dr -Ing. Bollar pointed out the efforts being made in China by implementing sensors in large numbers which is a good thing in the long run especially so as sensors are not very costly.

It was concluded that for structural health monitoring, the data driven approaches should be cross-checked with physics-based models.

Most of the panel experts agreed to continue the use of this kind of platform for discussion and to find an approach for solving various issues related to structures whether they are of aerospace engineering, high rise buildings and bridges, industrial infrastructures and components. The need of standardization in the field of structural health monitoring was felt by most of the experts.

Prof. Kapuria, summed up the Vertical 1 based on three points, viz., Development of SHM, change in the design philosophy to accommodate SHM and development of standards:

- R&D towards developing low cost and robust sensors
- Development of robust models that are data driven but with a protocol of checking with physics based models.
- Need for computationally efficient physics based models
- Striving for baseline-free methods or less dependence on baseline data
- Use of IIOT for monitoring a large number of structures/components
- Putting forth a convincing picture to owners of structures on the profit that they may gain, in terms of safety and value added to the structure, by implementing SHM tools
- Development of standards is very important especially so in civil engineering failing which implementation of SHM tools and techniques will be next to impossible

Setting the path for Vertical 2: Aircraft structures

- *Moderato*r: Prof. J. Jadav, Director, CSIR-NAL
- *Experts*: Prof. Victor Giurgiutiu, University of South Carolina, Prof. S. Gopalakrishnan, Indian Institute of Science, Prof. Roy Mohapatra, Indian Institute of Science and Dr –Ing. Christian Boller, Universitaet Saarland.

Views/Comments by Prof. Jadav : In his opening remarks, Prof. Jadav touched upon the current methods of inspection of military and civil aircrafts. He stated that, India is looking for algorithm with prognostic and diagnostic SHM for military aircrafts. He said the major areas to focus in future are the development of sensors (miniature ones) especially for metallic and composite structures and more work should be done towards developing model based systems as against data driven models.

Views/Comments by Prof. Giurgiutiu : Prof. Giurgiutiu said that the twin challenges faced by scientists and engineers in aerospace are safety and the media attention in event of an aircraft disaster. He said that because of the safety factor aerospace industry is very conservative though there has been a lot of development. He reiterated that, this industry is driven by safety, critical design and redundancy; and it will be a challenge to move from the conservative approach of inspection and maintenance to SHM. He also wondered on how the cost-benefit analysis could be done for this process, which is an important consideration for aerospace industry. Pointing out the safety factors which have been in practice for a long time he said that SHM research should get a physics explanation. He felt that, there is a need for interaction between academicians and designers about future research directions and goals. He empathetically stated that it is essential to base on SHM, an invaluable tool, on properly monitored data for bringing out safety factors rather than data based on economics or statistics.

Views/Comments by Prof. Gopalakrishnan : Prof. Gopalakrishnan agreed with Prof Giurgiutiu who emphasized on physics based modelling to build a good SHM system. Prof Gopalakrishnan voiced his concern about the awareness of SHM by certifying bodies and authorities in India. He concluded that there is a need for an all-round development and engagement with stakeholders such as regulatory and certification authorities, for the development and implementation of SHM especially with regard to imparting training programmes for aerospace engineers in India.

Views/Comments by Prof. Mohapatra : Prof. Mohapatra commented that further studies have to be done on how to move from a data driven model to physics based model and that factors such as risk and cost need to be studied more. Further he stated with regard to aircraft industries, specifically with reference to Line Replaceable Units (LRUs) where sensors cannot be placed. He went on to explain how indirect measurements by putting sensors around an existing certified sub system can reduce the burden of additional work and delay in qualifying new sensor

technologies which may be one way for collecting data on fault or defect. Explaining the reasons in the use of tapping method in inspection of aircraft he said that there are possibilities for piggy backing new sensor technology without tampering the baseline hardware which can be useful in circumventing some of the hurdles faced.

Views/Comments by Prof. Boller : Prof. Boller stated that quality and maintenance aspects with regard to civil engineering and aerospace engineering are very different as NDTs are comparatively new in civil engineering field. He stated that, there is a need for complete paradigm change for the implementation of SHM to work. He pointed out that identifying and putting to use the potential of SHM such as done by Delta airlines which has the oldest and biggest fleet is a good example fleet.

Prof. Jadav, summed up the Vertical 2 with the following points:

- On who decides the factors of safety and the long duration taken for changing the factor of safety which is based on a standard that was brought out in 1920s
- Involving decision makers such as regulatory and certification authorities who again depend on old standards
- Not easy to move to physics based model from data driven model as there are no sound knowledge base and sufficient validation of the model
- There is a need to change the mind set of people and certification authorities with regard to issues such as inspection procedures, etc.
- Further brainstorming in focussed way is required in this area

Setting the path for Vertical 3 **: Industrial machineries infrastructure and components**

- *Moderator:* Dr. Indranil Chattoraj, Director, CSIR-NML
- *Experts:* Dr Soumitra Tarfdar, CSIR-NML, Dr Somnath Bandopadhyay, CSIR-CGCRI and Dr Manjunath, CSIR-NAL.

Views/Comments by Dr. Chattoraj : Pointing out that, there is a lot of work going on in SHM, industrial components as well as structural integrity assessment. He called upon experts from the CSIR family to be a part of the panel for discussions. As the presentations on industrial components were limited in the programme, he set the context of the discussion by laying out the differences between SHM of industrial components vis-à-vis infrastructures and aircraft components. Enumerating this point further he said:

- Rate of failure of industrial components is much higher and need much attention and that failure of industrial components may not draw much

attention when compared to aircrafts though both may lead to monetary loss and loss of life

- Materials / components when they are in service face very severe environments such as very high temperatures, fuming gases and acids contained in a chemical reactor which bring about a change (microstructural, phase, etc) in the material/component

Hence he said that, attention should be first given to the issues that will be faced when looking for a baseline-free investigation or diagnosis and opened the discussion to the panellists.

Views/Comments by Dr. Soumitra : He opined that there is lot of commonality between aerospace and industrial structures/components and that because of the use of sophisticated materials such as composites, ceramics etc. a totally baseline free analysis may not be possible. Supporting the statement made by Dr Chattoraj on material changes due to environmental factors, he said that it is very important to have a "good understanding of the legacy…history of the development of this material degradation it would be very difficult to say where or how it is heading." He reiterated that baseline free methods/analysis need to be researched more. This statement was supported by Dr Chattoraj.

Views/Comments by Dr. Somnath : There is a need for standard procedure for metal casting. Industry can be categorized into two: the manufacturers and the exact users. Identify problems for which we can provide solutions, create a market and develop indigenous products. Regarding baseline analysis of materials and components, he said that the data on temperature achieved during the process of casting can be used to monitor the quality of casting. The moderator acknowledged this possibility of a baseline free approach in production of industrial components. Dr Soumitra added that it is essential to get the physics based of the problem, which will lead to understanding how nature of a material's degrades during the casting process.

Views/Comments by Dr. Manjunath : He said that with reference to overall SHM and in particular materials studies, there were two major issues, the first one being the diagnosis and how to identify changes in the structure using sensors. Secondly, there is a lot of work to be done with respect to prognosis. He also highlighted the importance of using physics based models and validating these models with empirical data and try to see what best unique solutions can be arrived at that can be applied to any type of materials and components.

Adding to the above discussion Prof Kapuria said that, there is no conflict as such between data-driven vs model-driven approaches. Physics-based models are always preferable for development of SHM methodologies. However, SHM is an inverse

problem and a large number for forward problems using the physics-based models are to be solved for being able to identify, locate and characterize damages from the measured sensor data. Such iterative solutions in real time can be time consuming (say in wave propagation based methods) and thus may not be suitable for real time detection. Therefore, there is a research need to develop computationally efficient physics-based models. Further, he said that the outcome of the data-driven models should be cross-checked with a physics-based model.

Appreciating this perspective Dr Chattoraj raised a question regarding the “holy grail “ of SHM that is high temperature sensing in relation to its current status and recent developments especially related to industrial components. Dr Somanth in his response said that first indigenisation of technologies available worldwide is very important and should be one of the outcomes of the present brainstorming session. Next, he explained the availability of instruments, although limited, available abroad which can measure very high temperatures. Further, some of the problems in high temperature sensing can be overcome by the use of fiber optics sensors.

On the discussion regarding the proliferation of IOT devices relating to SHM in India and what has been CSIR’s contribution and stand in this regard, the following were the points put forth.

- There is a lot of work being done in the area of IOT although the question on the readiness on the deployment in the industry needs more work especially for metallic structures to ensure the reliability after exploring the proven models that are already available. This can be one area where CSIR can focus.

- Along with software developers and a team comprising of sensor development interpreter, model developer, algorithm developer a complete IOT based solution for industrial purposes is possible.

Dr Somnath opined that when industry participation is anticipated then they should be categorised as partners who will come forward to manufacture/produce at the laboratory of the industry or from CSIR laboratories and the other as the user where the components will be deployed. Dr Somnath said that the users are willing to adopt indigenous products provided they are similar or better than the foreign ones.

EXECUTIVE SUMMARY By Prof. Santosh Kapuria

Prof. Kapuria thanked everyone for their participation in the historical brainstorming session undertaken by CSIR for the first time at the instance of the Hon'able Prime Minister of India, Mr. Narendra Modi and summed up the entire brainstorming session with the following observations in relation to SHM:

1. There were many significant inputs from the industry partners, who can be classified as users and co-developers. These inputs and those from more such interactions should form the basis of future R&D programs.

2. This group of experts created through this passionate and long brainstorming and the interactions should continue in a suitable form for taking the ideas further.

3. Take the ideas forward for solving problems by staying focussed and offering indigenous solutions on par with the internationally available technologies that are cost-effective and globally competitive and also in line with the needs of our country.

4. It is necessary to forge meaningful international collaborations, which will help in developing globally competitive futuristic technologies.

5. It is heartening to note that the key ideas that emerged from the detailed brainstorming are broadly in line with the approach paper that was shared earlier.

6. Both data based and model based approaches have their own significance and can be put to use in tandem.

7. It is important to strive for developing SHM technologies with least dependence on baseline information, if not completely avoided.

8. Development of cost-effective robust sensors, related hardware and SHM centric software is essential.

9. IIOT technologies need to be put to use as they are going to be an integral part of the future developments.

10. There is need to develop new design paradigms to reap the benefits of monitoring in the design, and also work on developing standards for the implementation of SHM in different kinds of structures and components.

Most of the panel experts agreed to continue the use of this kind of platform for discussion and finding an approach for solving various issues related to structures

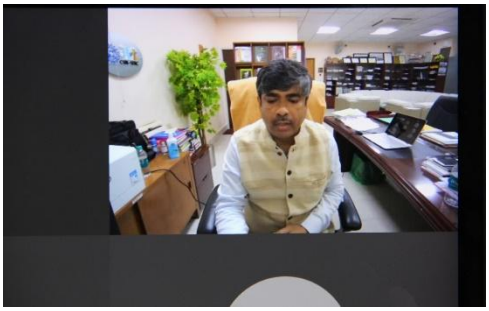
whether they are of aerospace engineering, high rise buildings and bridges, industrial infrastructures and components.

The need of standardization in the field of structural health monitoring was felt by most of the expert and it was committed by Director CSIR-SERC that he will initiate the work in this direction.

Dr.-Ing. Saptarshi Sasmal, Senior Principal Scientist and Head, Special and Multi-functional Structures Laboratory (SMSL), CSIR-SERC, proposed the vote of thanks.

Some Moments of Brainstorming

Welcome by Dr. R.K. Sinha



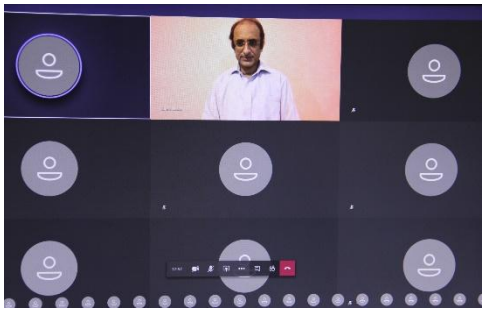
Inaugural remarks by Prof. Kapuria

Keynote lecture by Dr. Sekhar C. Mande

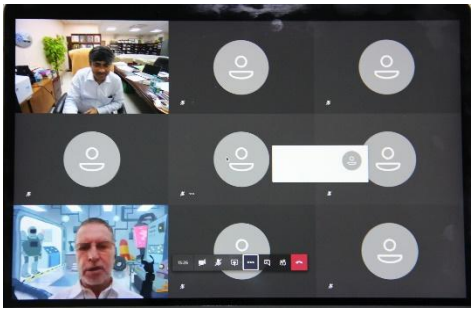
Setting the context by Prof. Kapuria

Prof. Tribikram Kundu and Prof.Fu-Kuo Chang

Prof. Christian Boller



Prof. Suresh Bhalla



Prof. Victor Giurgiutiu

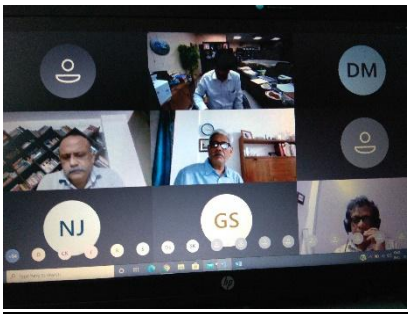
Panel Discussion for Vertical I:
Moderator: Prof. Santosh Kapuria

Panel Discussion for Vertical I:
Moderator: Prof. Santosh Kapuria

Panel Discussion for Vertical II:
Moderator: Shri Jitendra J Jadhav

Panel Discussion for Vertical II:
Moderator: Shri Jitendra J Jadhav

Panel Discussion for Vertical III:
Moderator: Dr. Indranil Chattoraj



Panel Discussion for Vertical III:
Moderator: Dr. Indranil Chattoraj

Programme Schedule

CSIR-Human Resource Development Centre, Ghaziabad
And
CSIR-Structural Engineering research Centre, Chennai
Jointly organizing

Brainstorming on'Structural Health Monitoring'
31 July, 2020 Platform: MS Teams

0930-1000 hrs	Registration/ Joining through MS Teams	
1000-1030 hrs	**Inaugural Session**	
1000-1010 hrs	Welcome	Dr. R K Sinha, Head, CSIR-HRDC
1010-1020 hrs	Inaugural Remarks:	Prof. Santosh Kapuria Director, CSIR-SERC
1020-1030 hrs	Keynote Address	Dr. Shekhar C Mande Secretary, DSIR and Director General, CSIR
1030-1130 hrs	**Brainstorming**: ***Setting thecontext***: 1030 -1050 Prof. Santosh Kapuria, Director, CSIR-SERC	
	1050-1110 -Prof. Tribikram Kundu (University of Arizona, USA) [Local time: 10:20 PM to 10:40 PM, July 30, 2020] 1110-1130- Prof. Fu-Kuo Chang (Stanford University, USA) [Local time: 10:40 PM to 11:00 PM, July 30, 2020]	
1130-1145hrs	**Break**	
1145-1330hrs	**Brainstorming- Session-I** : ***Understanding the need*** : Input from Industry 1145-1200 Dr. Mr. Vineet Srivastava, RDSO 1200-1215 Dr. V. Govindaraj, L&T 1215-1230 Dr. Arun, Honeywell 1230-1245 Dr. Arko Dasgupta, Mageba 1245-1300 Dr. Samuel Varghese, SFO Technology 1300-1315 Mr. R.S. Maurya, NTPC 1315-1330 Dr. Sanjay Chandra, TATA Steel	
1700-1900 hrs	**Brainstorming – Session-II** : ***Setting the goal*** : Input from academic expert 1700-1715 - Prof. S. Gopalakrishnan (Indian Institute of Science, India) 1715-1730- Prof. Suresh Bhalla (IIT Delhi, India) 1730-1745 -Prof. Dr.-Ing. Christian Boller (Universitaet Saarland, Germany) [Local	

	time: 02:00 PM to 02:15PM, July 31, 2020] 1745-1800-Prof. Ananth Ramaswamy (Indian Institute of Science, India) 1645-1800-1815- Prof. P. K. Biswas (IIT Kharagpur, India) 1815-1830-Prof. D. Roy Mahapatra (Indian Institute of Science, India) 1830-1845 -Prof. Ashok Saxena (University of Arkansas, USA)[Local time: 08:00 AM to 08:15AM, July 31, 2020] 1845–1900 Prof. Victor Giurgiutiu (University of South Carolina, USA)[Local time: 09:15 AM to 09:30 AM, July 31, 2020]
1900-1915hrs	**Break**
1915-2045 hrs	**Brainstorming – Session-III** : ***Setting the path*** : Panel Discussion
	1915-1945 hrsVertical: *Built up infrastructure* Moderator : Prof. Santosh Kapuria, CSIR-SERC
	1945-2015 hrs Vertical: *Aircraft structures* Moderator : Shri. J. Jadav, Director, CSIR-NAL
	2015-2045 hrs Vertical: *Industrial machineries infrastructure and components* Moderator : Dr. I. Chattoraj, CSIR-NML
2045-2055 hrs	Summing up and roadmap Prof. Santosh Kapuria, CSIR-SERC
2055-2100 hrs	Vote of Thanks Dr. Saptarshi Sasmal, CSIR-SERC

Approach paper
on
Structural Health Monitoring of Built-up and Industrial Infrastructure

In spite of extremely rigorous and stringent time-based maintenance regimes, and the most advanced analysis based design principles followed in some critical structures such as the aircraft, industrial structures, static equipment and process vessels, nuclear reactors, and space shuttles, catastrophic failures continue to take place claiming invaluable lives and critical engineering assets. Such failures bring to evidence a serious gap in today's science and technology capabilities. Conventional non-destructive evaluation (NDE) based maintenance can do little when flaws are induced and become critical between successive maintenance schedules.

In the last decade and half, there has been an overwhelming interest throughout the aerospace, civil and mechanical engineering communities, to address this issue by real time detection of damages at an early stage of their growth, which has led to the development of the general area of Structural Health Monitoring (SHM). It is essentially achieved by combining the conventional NDE with built-in actuators and sensors, and appropriate domain models and data analytics for feature extraction from the sensor signals for detecting, localizing and characterizing the damage. This leads to a paradigm shift from the regular schedule-driven maintenance to a condition-based as-needed maintenance regime. Apart from preventing catastrophic failure, a robust SHM strategy can provide several other benefits such as significant reduction in the downtime and enhancement of structural integrity, and increase in operating life of the structures. Further, the reports pertaining to life cycle cost analysis of structures indicate that it can indeed lead to significant cost effectiveness (for instance, about 50% savings in cost for wind turbines owning to the appropriate implementation of SHM).

Several infrastructural assets of our country (bridges, offshore structures, dams, power /petrochemical plants, refineries etc.) are steadily aging and deteriorating, and many of them are beyond their design life. Due to shortage of resources to replace them, it is now necessary to extend their design life without compromising the underlying human risk or incurring unnecessary financial burden. Deploying SHM solutions in these critical structures can eliminate or at least diminish the costly requirements of regular or exhaustive inspection and NDE, while ensuring their safe operations. Similarly, regular inspections of the cross-country pipelines (called the lifelines of a country) running for thousands of kilometres carrying oil and gas through intelligent pigging are both costly and may require operational shut-down, because of which there is a tendency for such inspections to be often delayed or held in abeyance. This may result in leakages or cracks that often cause devastating

fires and environmental damages. An appropriate SHM technology will be extremely useful for the safe operation of these pipelines, for which pipeline operators are in need of solutions. Further, an SHM strategy can bring the much needed confidence for adopting new generation materials such as fibre reinforced composites or advanced high strength steels or high temperature alloys capable of operating at still higher temperatures and pressure, since the higher cost of the material technology can be justified with the enhanced life of the structure, which is often more efficient due its lightness and/or operational capabilities.

A complete SHM solution would consist of (i) *damage diagnosis* involving identification, localization, sizing and characterization of damage, and (ii) *prognosis* which predicts the criticality of the damage and assesses the Remaining Useful Life (RUL) of the structure. While the prognosis is fairly well developed in many structures since it has been in use in conjunction with the conventional NDE, **it is the real-time/online damage diagnosis which is laced with several challenges, and needs to be focussed on for cutting edge futuristic development.** Advancements in the diagnostic abilities in turn may require the prognosis protocols to be revisited and redefined, since it would now be possible to locate and characterize the damage more accurately, and in almost real-time.

Depending of the type of the structure, e.g., beam-type (bridges, rails, rotating shafts), frame-type (building), plate-type (aircraft components, rotating blades), singly curved shell (pipelines), and doubly-curved shell (pressure vessels reactors), materials, functionality, and the operating and environmental conditions, the strategies for health monitoring differ in a wide range. While acceleration and strain time-history measurements may be effective for monitoring beam and frame type structures, high frequency guided waves are useful in detecting small damages in thin-walled (plate/shell) structures. Similarly, there may be a need of specialized sensors in harsh corrosive and high temperature environments. The techniques of SHM also vary for different kinds of problems/objectives such as the global monitoring of massive structures, large area monitoring of larger structures, condition monitoring of rotating machines, and local monitoring of known hotspots (e.g. weldments) in sensitive components. Each of these cases are associated with a different set of challenges, which needs to be looked into details.

Most of the available SHM methods need the baseline (reference) data from healthy/pristine conditions and the changes in the current response signals from the baseline data are used to identify the presence of damage. A major concern with all the baseline based SHM methods is that the baseline signals acquired in the healthy structure may undergo changes due to the change in the environmental and operational conditions, which may lead to false alarms for damage. Robust compensation techniques for such changes, though have been attempted, are always tricky. Moreover, in many cases, the baseline data on the pristine state of the in-service structure may not be available at all. In view of this, the focus for future

development should be to develop baseline-free techniques which can provide technological breakthroughs and create a big impact on the state-of-the-art in monitoring the critical infrastructure. Further, some of the other futuristic trends are output-only methods, population based methods, machine learning algorithms, distributed fibre optics sensing for long structures, vision based sensing, optimal sensor placement, sensor fault detection, and use of IOT platforms for wireless sensing and data transfer. In addition, there are data driven methods, model based techniques as well as hybrid techniques. In case of model based or hybrid techniques and also for designing data driven models, efficient (fast) and accurate computational models are needed to developed, which too is another futuristic area of work. Material models also need to be developed that can predict the intrinsic resistance of the material in its current microstructural state to further damage and degradation without the requirement for *a priori* knowledge of the material's original microstructural state.

Aggressive and sustained R&D efforts are currently underway across the globe on developing robust SHM technologies. In this context, it is imperative that CSIR timely exploits its multi-disciplinary capabilities for a **globally competitive futuristic technology development initiative on Structural Health Monitoring of Built-up and Industrial Infrastructure for both civil and strategic applications**. CSIR should aspire to be a global leader in identified areas so as to make indigenous state-of-the art technologies available for the country's infrastructure health monitoring at reduced cost, and prevent loss of lives and properties, and achieve efficient utilization of infrastructural services ushering in faster industrial growth, emphasizing the relevant priories, including SDGs, set by Government of India.

Existing Capabilities of CSIR Laboratories:

A number of CSIR laboratories are involved in R&D activities on health monitoring of buildings, bridges, roads, railways, plant machineries, aircrafts and other infrastructural elements. CSIR-SERC has pioneered in developing the computational and experimental techniques for health monitoring of large structures. In a recently completed mission project, important leads have been obtained on some of the futuristic areas like baseline-free techniques for bridges, guided-wave based methods for thin-walled structures, distributed fibre optics sensing based method for long pipelines, advanced output only time-series algorithms, acoustic sensing of damage imitation, etc. CSIR-NAL has proven expertise in the field of health monitoring of advanced composites structures using online & offline approaches, sensor development for aircraft components and vehicle health management. CSIR-NML has been a leading player in integrity assessment of pressure vessels, rotating equipment, nuclear and thermal power plant components and other components based on response measurements. It has also been a pioneer in development of sensor, sensor-based devices and protocols based on ultrasonics, eddy current, FBG and magnetic materials based technology. CSIR-NML has led pan-CSIR

technology based structural integrity initiatives contributing directly to industries and providing industrial solutions during the 10th and 11th Plan periods. CSIR-CGCRI has developed different types of sensors and sensor packages for various applications like power plant machinery, civil structures, steel plants etc. The innovative design, fabrication and characterization capabilities for FBG sensors will considerably help in developing capabilities for indigenized sensors for discrete and distributed sensing. CSIR-CEERI has been involved in the development of embedded platform, sensor networks and machine learning algorithms for various applications from past several years, and in recent years, it has developed AI based diagnostic tools and IoT-Cloud enabled integrated online SHM framework for infrastructure. These unique capabilities and rich expertise of the different CSIR laboratories provide a perfect foundation to launch a comprehensive interdisciplinary program for the development of globally competitive and futuristic SHM technologies in close collaboration with the industries, infrastructural asset owners as well as external experts from India and abroad.

Primary focus:

- Indigenous development of advanced sensors such as FBG fibre optic sensors, Brillouin distributed fibre optic sensors, high temperature sensors, micro-fibre-composites (MFCs) and magnetic materials based sensors, including related signal acquisition and processing hardware. Certification of sensor and related hardware on needs to be addressed.
- Optimized sensor placement schemes for damage detection based on; (i) damage history and accessible locations in case of builtup structures, (ii) damage threat perspective for new structures
- Baseline-free and output-only real time SHM techniques for detection, localization and characterization of damages (diagnostics) in varied types of infrastructure and aircraft structures and their components
- Data-driven damage localization and quantification methods for SHM using AI techniques.
- Computationally efficient and accurate simulation models for model-based SHM techniques and design of data-based SHM techniques.
- Integrated technology for diagnosis and deterministic/probabilistic predictive modelling of performance of critical components of industrial machineries, process vessels/reactors and equipment,
- Indigenously developed IOT-cloud-based real time SHM platform for infrastructure

The proposed verticals

- Vertical 1: Built up infrastructure (Lead - CSIR-SERC)

- Vertical 2: Aircraft structures (Lead - CSIR-NAL)
- Vertical 3: Industrial Infrastructure and Components (Lead - CSIR-NML)

Other Labs to be involved: CRRI, CBRI, CMERI, CGCRI, CEERI, CECRI, CSIO, CIMFR, 4PI

Each vertical will have horizontals related to: (i) Sensors/electronics, (iii) Data acquisition, communication and processing, (iii) Feature extraction algorithms including AI, (iv) Analytical and computational modelling, and (vi) Predictive models.

Industry connectivity

The proposed development will cater to civil infrastructure, mobility infrastructure including railways, aerospace, oil & gas, petrochemicals, thermal power, nuclear power and process industries. Sector specific industries relevant to the identified verticals need to be involved from the initial stages of conceptualization of the initiative, for interactions and implementations of ideas/issues to develop implementable and scalable solutions to meet the industrial needs.

CSIR-Human Resource Development Centre (CSIR-HRDC), Ghaziabad

Brainstorming on 'Utilization of Agro/Biomass waste: Roadmap & Strategy'

28th October, 2020, Platform: MSTeams

- For the utilization of Agro/ Biomass Waste, Organic waste management system is required
- Agro Bio-mass conversion to fine chemicals
- Products targeted towards Organic Municipal Solid Waste/ Agro-waste & soil Conditioner
- Strategies to implement the developed technologies on organic waste management
- L-Asparaginase (HIMASNASE) form food processing applications
- Levulinic acid production from bio-mass
- Eco-friendly process for fibre extraction from underutilized bio resource
- Value added products from animal waste
- Nano cellulose from Agro waste
- Ecological construction materials from Agro waste (Parthenium)
- Crispy fruits and vegetable technology for reducing post-harvest losses
- Floral waste to incense cones
- Need for the development of new class of hybrid green composites
- Need to develop manufacture sustainable materials from paddy straw leading to local employment, income generation & livelihood improvement
- Transforming waste into wealth in construction sector
- Create start-up industries, thus enhance economy & employment
- High rate biomethanation of agricultural waste in India: An economically viable and remunerative solution
- In order to process stubble, there is need to start the collection of stubble from farmers and to process it and transfer it to the industry and the market. For this we need to involve farmers first, then the state government/ municipal corporations, and then comes the R&D institutions like CSIR, then the industry and then the market of product.
- Future biorefineries concept based on biodiesel
- Natural product extraction energy can be utilized for process operation
- Technologists, engineers have to work together to come up with better pre-processing solutions.
- Government stake should exist
- De-risk the farmer and entrepreneurs
- Oil and gas companies to step up further- increase off-take price and pick CBG from the plant.

- FCO notification/ recommendation on solid bio-fertilizer. Liquid slurry is still largely ignored.
- Integrated approach is extremely important. One single technology cannot be a solution to this massive problem of Agro waste.
- Wet agro waste is available in huge stock in the country. A number of technologies have to come into place.
- For Agro waste, the collection, procurement and transportation to the tech centres play a key role.
- Cost of procurement and transportation is to be taken care of. The logistics is expensive.
- The availability of raw material needs to be continuous so that the industry doesn't goes down during any point of time.
- Farmers should be given incentives so that the crop comes well grown at the end of the day and because the farmers are important but they're not given the importance they deserve today.
- There is a need to set up distributive plants, we do not always need to set up large scale plants wherein collection of waste become a big logistic. Setting up distributive plants can reduce around 20 to 30 percent of logistics cost.
- Integrated solution and strategy on Agro/ Bio-wastes throughout the country has to be developed and has to include various national and international stakeholders. This would help in achieving a bigger goal.
- Change the mind-set from weeding or destroying water hyacinth to harvesting under control

Brainstorming on 'Personal Care, Flavour and Fragrance

Date: 31.08.2020

Experts drawn from: Emami, Dabur, Fragrance and Flavour Association of India, Jindal Drugs, Indian Society of Cosmetic Chemists, Gattefosse India Ltd, Ultra International, Essential Oils Association of India

Recommendations:

- Famers to be educated about adopting the suitable crop for geo-specific specific climatic conditions for maximum utilization of natural resources;
- Joint council of CSIR laboratories with various stake holders including Producers, Regulators and Research organisations
- Special training programs on cosmetics for young researchers
- C-14 Carbon Dating Test in CSIR for identification of any synthetic contaminants

Major points discussed during brainstorming session are issues related to technology, sewerage and sludge management. Recommendations discussed by the Experts are listed as follows:

1. Waste Collection network systems are still not located in proper place in slum areas especially in urban centers.
2. Meeting the discharge norms and operation of STPs amidst of frequent failures in urban and semi-urban centers are real challenges.
3. Difficulties in meeting the fund deficit in various stages (i) from proposal stage to the approval stage and (ii) during implementation stage of the STPs - by the various State Governments.
4. Need for Revision of CPHEEO manual and experts from different domains have been discussed. Experts from different organizations have to be involved in revision of CPHEEO manual for incorporation of recent technological developments Treatment and disposal of sludge generated from treatment plants especially STPs/ CETPs is the need of the hour and has to be decided based on the sludge characterization and quantification.
5. There is an immense need for training of personnel with adequate qualification for O& M of STPs/ CETPs which is lacking in most of the places.

6. Similar to ISO Certification, some sort of accreditation/ empanelment / Certification may be provided to the O & M Personnel of the STP and Industrial Effluent Treatment plants. Engagement of such certified man power can be mandated / insisted to a specified extent, in the treatment plants,

7. Establishment of Analytical labs can be considered, in STPs and Industrial Effluent Treatment plants, for better monitoring the performance of the treatment process on day to day basis.
8. Third party assessment/audit of STPs/CETPs/ ETPs may also be insisted.
9. Scope for creation of Job opportunities for qualified and certified personnel in STPs/ ETPs/CETPs has been discussed.
10. Preference can be given for selection of Indigenous electro-mechanical equipment's to minimize the capital cost, O & M cost of equipment's so as to minimize not only the cost but also the down time of the equipment.

RECOMMENDATIONS FROM BRAINSTROMING SESSION ON 'LIGHT WEIGHT MATERIALS: METAL FOAMS'

8thJuly, 2021, Platform: MS-Teams

- Prepare a road map to accelerate the high-end science and innovative research in the field of Metallic Foams.
- Form a working group with one scientist from each lab and this group will be charged with the responsibility of preparing a DPR and a Road Map for the development of Metal Foams for various applications and take it to the Industry for commercial production.
- Identify the Institutes/Industries working in the field of metal foams development and this working group will collaborate with them to fill the knowledge gap between Institute/Academia and Industry. This will translate the lab research and scale up the technology with the help of manufactures to meet the end user demand. The responsibilities for each participating institute/Industry should be assigned according to their specialization.
- Product development based on industry/stakeholder's requirement.
- Emphasis shall be put on the development of facilities which will cater the need to characterization of these foams at high strain rate for their applications in defence and automotive sector to promote the "Atmanirbhar Bharat Abhiyaan".
- Create the Centre for Excellence where common facility will be maintained for sophisticated and analytical equipment so that proper utilization of the facility can be achieved.
- Data generation is important and creation of standards too.
- Prepare List of applications of metal Foams and set a bench Mark for each application.
- The work on Foam Panels for Structural applications and Foam Filters for use as filters in both gas and liquid medium for future endeavours.
- Design and fabrication of foam filled components. This is more challenging than producing foams.
- Development of continuous or semi-continuous process for foam processing. Without this a large-scale production cannot be realized.

- Exploring advanced processing techniques such as additive manufacturing.
- Adequate study on post production and manufacturing of Metal Foams.

ROAD MAP (2020 – 2030) : BS meeting driven Recommendations

Lithium-ion battery Technology will remain UNBEATABLE (wrt. Superior Energy density & hence Energy Storage also)

Lithium-ion battery will dominate as the ENERGY STORAGE solution (at least) for another 10-15 years

Simultaneous development of Sodium-ion battery technology is mandate

Energy Density target of 200 Wh/Kg should be fixed for sodium-ion technology & to be realised within next 5 years

Redox flow batteries (Larger & Grid storage) and Recycling of batteries (Sustainability) are to be prioritised with immediate effect

Metal-Air / All solid state batteries require 1-2 decades for real-time applications, provided R&D is geared up from now onwards

As far as LIB technology for real-time application (EV / Consumer market based e-gadgets) is concerned,
LFP Vs. LTO (Grid Storage) , LFP vs. Graphite & NMC Vs. Graphite are the potential / proven systems of choice

Research on Cobalt-free lithium battery cathode and Platinum-free fuel cell electrode has to be PRIORITIZED

Indigenous Battery-grade Electrolyte preparation (chemical / electrochemical) needs to be initiated

50% of battery cost – Cost of the CATHODE - Technology on LIB cathodes needs to be commercialised with global benchmarking

Battery Chemistry, Battery Engineering & Battery maintenance / management – to be educated in Schools, Colleges, Diploma and Degree students, Higher studies / Research scholars; Hands-on training to be imparted to Indian Youth (like A/C mechanic)

ROAD MAP (2020 – 2030) : BS meeting driven Recommendations

- Storage under two forms, viz. Electrochemical (Batteries) and Hydrogen Storage – needs to be focussed
- Fuel switching using Green Hydrogen and Simultaneous development of Electric Grid and Hydrogen Grid are important
- Hydrogen, the BRIDGE between conventional and renewable energy sector has to be supported for Generation, Storage and Application in Stationary and Mobility point of view [Hydrogen cycle with PEM fuel cell & Water Electrolyser – to be proven]
- Renewable Natural Gas (RNG) & Methanol as Hydrogen carrier - should be the Mantra for next few years
- Bio fuel transportation / commercialisation, sustainable and continuous storage : India-centric plans to be implemented
- Development of Third Gen. PV and Standards for PVs are to be given prime importance
- Power electronics has to be integrated and strengthened in all types of energy generation, conversion and storage devices
- Energy Audit is to be done nation-wide, PAN CSIR level, Institute / Industry / individual technology-wise also
- Team of Energy Auditors has to be generated through trainings and on-site hand-holding practises
- Energy efficient effluent treatments are to be supported - Umbrella Action Plan may be designed and implemented
- Prototype developments /Fabrications may be outsourced on select cases to speed up the commercialisation of technology

ROAD MAP (2020 – 2030) : BS meeting driven Recommendations

Innovation is required from Incremental to Disruptive: Balance between fundamental & real-time applied science to be ensured

Infra structure for Mass production & Facility creation for Testing / Certification – to be created for large scale validation

Technology Development and Market Penetration through Commercialisation of product – Existing gap needs to be addressed

Like TRL, Manufacturing Readiness Level (MRL) is also equally important – necessary focus and priority to be given by the GoI

MRL support platforms to be created with liberal financial support from CSIR / Ministry / GoI through policies

Seasonal variation and Renewable energy capture has to be regularised through incentives and attractive schemes

COST OF ELECTRICITY - to be reduced / subsidised / ratified for renewable energy generation / conversion / storage attempts

Skill building & Capability building in RE, Gas grid expansion to meet out next 100 years demand are to be prioritised from now

TRL: 1-3/4 (CSIR); TRL: 4-6/7 (CSIR-Industry Collaboration) & TRL: 7-9 (Consortia of Line Ministry, CSIR & Industries)

Annual Meet / Annual benchmark performance check / Industry sponsored Research scholars / Innovation Awards – Mandate

Making Indigenous Technologies Cost-effective & Market Acceptance for Make in India products – GoI intervention is required

CoE and Fellowships through Alliance such as IESA, etc. to be recommended and sought for. **Beyond CSIR** approach is essential.