Smart Materials, Structures and Systems (SMSS) Laboratory

Laboratory Coordinator: Dr. Bishakh Bhattacharya

Associated Faculty Members (if any):

Website: https://www.iitk.ac.in/smss/

List of Major Equipment:

- 3D Laser Doppler Vibrometer,
- Acoustic Camera
- GPU Cluster – Server
- ViperX 300 Robot Arm 6DOF
- 3D Printers - Creality Ender-3 V2 and Ultimaker 3 Extended
- d33 PiezoMeter Systems - PM300
- Amplified Piezo Actuator
- Intel® RealSense™ Tracking Camera
- Vibration Exciters - LDS Shaker V101, V201 and Modal Exciter 2025E
- dSpace ACE 1103, 1104, Multi-channel SMA amplifiers
- Magnetic Levitation Control
- Accelerometers and Force Sensors ICP
- 4 channel active vibration control system
- Data Acquisition System: Graphtec GL2000
- Micro Syringe Assembly GS1200
- Laser Distance Meter

Brief description of the laboratory:

Please provide a brief description of the laboratory in about 8-10 lines, focusing on the main thrust area of the laboratory activities.

Smart Materials, Structures and Systems (SMSS) Lab actively works towards novel scientific and technological inventions. SMSS lab works in a diverse field ranging from smart materials (Shape Memory Alloy, Piezoelectric) and metastructures to robotics and neuronal modelling. Over the past two decades, SMSS lab in the department of Mechanical Engineering at IIT Kanpur, has excelled consistently in various domains of mechanical science, at national as well as international levels. The lab has a long-standing reputation of grooming quality engineers and motivated researchers. Research activities and facilities in SMSS lab attract many aspiring students and research scholars across various disciplines. This lab is an epitome of working towards the betterment of society and nation-building through technological innovations and transfer.

Laboratory research keywords:

Shape Memory Alloy; Robotics; Metastructure; Vibration & Control; Dynamical System; Telemedicine & Prosthetics; Neuronal Modelling; Cognitive Science.

Major Research and Development Contribution of the Laboratory

Year	Major research and development activity
2020-2021	▪ Bioinspired SMA based Actuator o Objective - DC motor-based actuators are being widely used in various fields; however, they mostly depend upon the embedded gear train mechanism to provide required torque output. The use of gear trains, in turn, increases the cost, size, and weight of the actuators. Therefore, the current project proposes to provide a solution to tackle the challenge. The idea behind the project is based on the biomimetic approach, which provides an abundance of designs and solutions which are optimized and efficient in nature to solve complex human problems. The solution to this problem can be obtained from the biomimicry of muscles located in the human body. These types of muscles generally allow higher force production but a smaller range of motion. The design of muscle provides the flexibility of controlling the length of fiber (in our case, SMA wire) to obtain the torque requirement without having any significant effect on the overall dimensions, weight, and cost of the actuator. o Research Impact – ▪ Kanhaiya Lal Chaurasiya, A. Sri Harsha, Yashaswi Sinha, Bishakh Bhattacharya (2022). Design and development of non-magnetic hierarchical actuator powered by shape memory alloy based bipennate muscle. Scientific Reports. ▪ Bishakh Bhattacharya, A Sri Harsha, Kanhaiya Lal Chaurasiya (2021). Shape Memory Alloy Embedded Bipennate Actuator System for Enhancing Output Torque or Force. IPA: 202111028327. ▪ Bishakh Bhattacharya, Kapil Das Sahu, Kanhaiya Lal Chaurasiya, Ujjain Kumar Bidila, P Mani Kumar, Johnson Controls (2021). AN ACTUATOR FOR A VALVE. IPA: 202111039151 ▪ Cognitive Robotics based study of Child-Robot Interaction (CRI) - Characterization of Critical Parameters and Interaction Design o Objective - The principles of Child-Robot Interaction is yet underdeveloped and a lot of work is in progress to develop the foundation. Though rapid progress in the field of artificial intelligence is paving a path towards the goal, that machines becoming adaptively intelligent, the complexity associated for designing such a framework is increasingly challenging. Humans subconsciously adapts their behaviour to the surrounding environment to make the interaction run smoothly. Replicating such smooth interaction is difficult for a machine (Robot). The challenge lies in the parameter identification for interactions and subsequently designing an efficient model to handle the same. For an adult these models are even more complex than a child owing to the order of heterogeneity associated with these

	interactions. This project aims to study several critical parameters that affect interaction with Robots for children with different age groups and develop suitable models that helps in implementing smooth and untethered interaction. Several physical design related issues of a Robot along with the capabilities that enhances interaction will be studied in an experiment based setup. Pre-defined interaction through a Robot (NAO) will be programmed and subjects (children with several age groups) will be engaged with the same. The response from the subjects will be recorded and analysed with the state-of-art data analytics tools to draw inferences. The inferences will help in modelling a more socially adaptive robot and also identify active and passive characteristics that should be inculcated in the Robot's hardware and software designs. o Outcome – ▪ Developed a Reinforcement Learning (RL) based model for the robot to react in a trustworthy manner while interacting with children ▪ Replicated human-like gestures in the NAO humanoid robot for different emotions ▪ Design and Developement of Autonomous Power Substation Inspection Robot o Objective: POWERGRID is presently operating 1,70,224 ckms of transmission lines along with 262 substations with 4,51,351 MVA transformation capacity. To maintain such vast network with more than 99% availability, it is challenging and requires lot of resources. Substations are the nodes of electrical grids, ensuring reliability, efficiency, and sustainability of electricity transmission and delivery. In order to address the demands that arise during construction, refurbishment, and operation and maintenance (O&M) of substations, substantial efforts have been made to develop robots capable of assisting or replacing engineers in the performance of repetitive and/or dangerous tasks comprising the substation lifecycle. A further advantage of O&M robotics is that it can increase availability, as many facilities are unattended, yet must be continuously operational. POWERGRID and IIT Kanpur are jointly developing an autonomous mobile robot for inspection of substations to take care of repetitive and time-consuming inspection activities on a regular basis. The robot will be equipped with a wide array of sensors (IRIS control cameras, IR thermal sensors, LIDAR, fire alarms) and an autonomously (along with tele-operation feature) navigating platform which will roam around a substation and perform regular inspection for any damages in components that are essential for continuous running of the sub-station o Outcome – The robot will utilize advanced vision processing and machine learning algorithms to independently identify and flag any damages or failure to any critical components in the substation and

	automatically trigger an alarm. Use of such robot will also allow ground staff to access areas in a substation that are manually difficult to inspect. The robot will be trained using condition monitoring algorithms based on machine learning. This will enable the robot in damage identification, classification and prognosis of every sub-system. The procedure will upgrade the maintenance from routine monitoring to a continuous monitoring system and enhance the life of the components significantly.
2019-2020	▪ Design and Development of Autonomous Robot for Crop-Monitoring and Localized Pest Neutralization o Objective: ▪ Monitoring local conditions (temperature, humidity etc.) in the farm ▪ Autonomous navigation (manual override option available) ▪ Smart sensors (high resolution camera) and algorithms (AI/ML based) to detect local infestation of crops ▪ Efficient deterrence by localised pesticides delivery mechanism to the affected area ▪ Advance precision farming technique ▪ Display for real-time image feeds from inaccessible regions on the farm o Research Impact: ▪ Mahendra Kumar Gohil, Anirudha Bhattacharjee, Bishakh Bhattacharya, Samir Kumar Biswas (2022). A ROBOT SYSTEM FOR AUTOMATICALLY MANAGING AGRICULTURAL ACTIVITIES. IPA: 202211034166. ▪ Mahendra Kumar Gohil, Aniruddha Bhattacharjee, Divya Jyoti Pandey, Chetan Vashishtha, Bishakh Bhattacharya (2021). A SYSTEM FOR FACILITATING TWO-DIMENSIONAL FLUID MOVEMENT OF AN OBJECT OVER AN AREA. Patent No: 401748. ▪ Pipe Health Monitoring Robot (PHMR) o Objective: The project aims at developing a pipe health monitoring system based on smart sensors which can be transported inside compressed gas pipes with the help of a conduit crawler robot to determine the extent of anomalies present in the pipeline. The pipe health monitoring system will comprise a sensor network for anomalies detection, a micro-controller for processing the data from various sensor units and a storage unit to store the processed data, and an autonomous platform or robot, to carry these components inside the pipeline.

	○ Research Impact: ▪ Santhakumar Sampath, Kanhaiya Lal Chaurasiya, Pouria Aryan, Bishakh Bhattacharya (2021). An innovative approach towards defect detection and localization in gas pipelines using integrated in-line inspection methods. Journal of Natural Gas Science and Engineering. ▪ Santhakumar Sampath, Bishakh Bhattacharya, Pouria Aryan, Hoon Sohn (2019). A Real-Time, Non-Contact Method for In-Line Inspection of Oil and Gas Pipelines Using Optical Sensor Array. Sensors ▪ Kanhaiya Lal Chaurasiya, Bishakh Bhattacharya, S Barathy, Sanjeev Kumar (2020). Speed Control System for Pipe Health Monitoring Robot. IPA: 202011016379. ▪ Bishakh Bhattacharya, Nachiketa Tiwari, Nayan Jyoti Baishya, Himanshu Panday, Vaibhav Verma, S. Barathy, Raj Kumar Kashyap, Parivesh Chugh, T.P. Yuvaraj, Pushpit Kant, Sumit Kumar (2015). A Novel Self Powered, Intelligent Pipe Health Monitoring Robot (PHMR) for Inspecting Gas Pipe Line. Patent No: 403841.
2018-2019	▪ Smart Stick ○ Objective: This project aims to develop a smart, adaptive, and intelligent walking aid for elderly people, which can provide adequate force in a Sit-to-Stand and vice-versa transfer. The proposed device is equipped with sensors and intelligent algorithms that actuates itself adaptively to provide the force deficiency that older people encounters while executing the daily activities. Sit-to-stand or stand-to-sit (STS) motion is a very common and vital activity in everyday mobility. Elderly people often looks for external help/support to gather adequate support to execute the same. This project intends to develop a smart adaptive walking aid for elderly people equipped with sensors and feedback mechanism that actuates itself adaptively to provide the force deficiency. ○ Outcome: ▪ Adaptive reconfigurable STS smart walking assistance stick with active actuation to adjust height ▪ Sensors and learning algorithms to train to provide personalized comfort. ▪ Gait calibrated auto adjustment of momentum transfer for effortless walking assistance. ▪ Smart stick integrated with auto calibration. ▪ Uniquely designed vibration dampers (honeycomb flex) integrated to prevent shock and falling.
2017-2018	▪ Design of shape memory alloy actuated intelligent parabolic antenna for

space applications

- Outcome: The deployment of large flexible antennas is becoming critical for space applications today. Such antenna systems can be reconfigured in space for variable antenna footprint, and hence can be utilized for signal transmission to different geographic locations. Due to quasi-static shape change requirements, coupled with the demand of large deflection, shape memory alloy (SMA) based actuators are uniquely suitable for this system. In this paper, we discuss the design and development of a reconfigurable parabolic antenna structure. The reflector skin of the antenna is vacuum formed using a metalized polycarbonate shell. Two different strategies are chosen for the antenna actuation. Initially, an SMA wire based offset network is formed on the back side of the reflector. A computational model is developed using equivalent coefficient of thermal expansion (ECTE) for the SMA wire. For power-minimization, an auto-locking device is developed. The performance of the new configuration is compared with the offset-network configuration. It is envisaged that the study will provide a comprehensive procedure for the design of intelligent flexible structures especially suitable for space applications.
- Research Impact:
    - Kalra S, Bhattacharya B, Munjal BS. Design of shape memory alloy actuated intelligent parabolic antenna for space applications. Smart Materials and Structures. 2017 Aug 9;26(9):095015.
    - Kalra S, Bhattacharya B, Munjal BS. Development of shape memory alloy actuator integrated flexible poly-ether-ether-ketone antenna with simultaneous beam steering and shaping ability. Journal of Intelligent Material Systems and Structures. 2018 Nov;29(18):3634-47.

- Exploring the dynamics of hourglass shaped lattice metastructures
    - Objective: Continuous demand for the improvement of mechanical performance of engineering structures pushes the need for metastructures to fulfil multiple functions. Extensive work on lattice-based metastructure has shown their ability to manipulate wave propagation and producing bandgaps at specific frequency ranges. Enhanced customizability makes them ideal candidates for multifunctional applications. This paper explores a wide range of nonlinear mechanical behavior that can be generated out of the same lattice material by changing the building block into dome shaped structures which improves the functionality of material significantly. We propose a novel hourglass shaped lattice metastructure that takes advantage of the combination of two oppositely oriented coaxial domes, providing an opportunity for higher customizability and the ability to tailor its dynamic response. Six new classes of hourglass shaped lattice metastructures have been developed through combinations of solid shells, regular honeycomb lattices and auxetic lattices. Numerical simulation, analytical modelling, additive layer

	manufacturing (3D printing) and experimental testing are implemented to justify the evaluation of their mechanics and reveal the underlying physics responsible for their unusual nonlinear behaviour. We further obtained the lattice dependent frequency response and damping offered by the various classes of hourglass metastructures. o Research Impact: ▪ Vivek Gupta, Sondipon Adhikari, Bishakh Bhattacharya (2020). Exploring the dynamics of hourglass shaped lattice metastructures. Scientific Reports. ▪ Vivek Gupta, Sondipon Adhikari, Bishakh Bhattacharya (2020). Locally resonant mechanical dome metastructures for bandgap estimation. Active and Passive Smart Structures and Integrated Systems IX. ▪ Vivek Gupta, Anwesha Chattoraj, Arnab Banarjee, Bishakh Bhattacharya (2019). Wave propagation in auxetic mechanical metamaterial: Bloch formalism for various boundary conditions. Active and Passive Smart Structures and Integrated Systems XIII.
2016-2017	▪ Dual Functional Metamaterials and Metastructures for Energy Harvesting and Vibration Control o Objective: The dynamics of periodic materials and structures have a profound historic background starting from Newton's first effort to find sound propagation in the air to Rayleigh's exploration of continuous periodic structures. This field of interest has received another surge from the early 21st century. Elastic mechanical metamaterials are the exemplars of periodic structures that exhibit interesting frequency-dependent properties like negative Young's modulus and negative mass in a specific frequency band due to additional feature of local resonance. It implies, the spatial periodicity of mechanical unit cells in engineered metamaterials exhibits properties beyond one can expect from conventional naturally occurring materials. Locally resonant units in the designed metamaterial facilitate bandgap formation virtually at any frequency for wavelengths much higher than the lattice length of a unit cell. Whereas at higher frequencies for wavelengths equal to the lattice size of the medium, the Bragg scattering phenomenon occurs, which also helps in the bandgap formation. Due to out of phase motion of multiple resonating units with lattice, there is a change in the dynamic behavior (stiffness or mass) of the material as physical properties become frequency-dependent. o Research Impact: ▪ Ankur Dwivedi, Arnab Banerjee, Bishakh Bhattacharya (2020). A novel approach for maximization of attenuation bandwidth of the piezo-embedded negative stiffness metamaterial. Active and Passive Smart Structures and

	Integrated Systems IX. ▪ Ankur Dwivedi, Arnab Banerjee, Bishakh Bhattacharya (2020). Simultaneous energy harvesting and vibration attenuation in piezo-embedded negative stiffness metamaterial. Journal of Intelligent Material Systems and Structures. ▪ Ankur Dwivedi, Arnab Banerjee, Bishakh Bhattacharya (2019). Study of piezo embedded negative mass metamaterial using generalized Bloch theorem for energy harvesting system. Active and Passive Smart Structures and Integrated Systems XIII.
2015-2016	▪ Cabin Pressure Control System (CPCS) o Objective: Cabin pressure control system of an aircraft maintains cabin pressure in all flight modes as per the aircraft cabin pressurization characteristics by controlling the air flow from the cabin through the outflow valve of the cabin pressure control valve. The movement of outflow valve in turn depends on the air flow from the control chamber of cabin pressure control valve, which is controlled by the clapper and the poppet valves. These valves are actuated by absolute pressure and the differential pressure capsules, respectively depending upon the operating flight conditions. Mathematical models have been developed to simulate the air outflow rates from the cabin and the control chamber of cabin pressure control valve during steady-state and transient flight conditions. These mathematical models have then been translated into a MATLAB program to obtain plots of cabin pressures as a function of aircraft altitudes. The mathematical models are validated for standard cabin pressurization characteristics of a multirole light fighter/trainer aircraft. The model developed, thus can be used to produce a number of variants of cabin pressure control valve to suit different cabin pressurization characteristics. o Research Impact: ▪ Kanhaiya Lal Chaurasiya, Bishakh Bhattacharya, A K Varma, Sarthak Rastogi (2020). Dynamic modeling of a cabin pressure control system. Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering.

Figure #1: Design and Development of Autonomous Robot for Crop-Monitoring and Localized Pest Neutralization

Figure #2: Design and development of non-magnetic hierarchical actuator powered by shape memory alloy based bipennate muscle.

Figure #3: Design and Development of Aquatic Autonomous Observatory (Niracara Svayamsasita VedhShala - NSVS) for In situ Monitoring, Real Time Data Transmission and Web based Visualization.

Figure #4: 8-inch pipeline test-bed facility with air compressor operational at Department of Mechanical Engineering, IIT Kanpur

Figure #5: Exploring the dynamics of hourglass-shaped lattice Meta structures