ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 3, Issue 5 , May 2016

Literature review of Smart Materials / Actuators / Sensors in the Design of Smart flexible life saving Robots

Pundru Srinivasa Rao

Associate professor, Department of Mechanical Engineering, Mahatma Gandhi Institute of technology
Gandipet, Hyderabad-500 075, Telangana State, India

ABSTRACT: The physical structures of these smart flexible life saving robots are like amoeba, which can move–roll-jump and change its configuration such as assembling and disassembling of its components which depends on its requirement. It is very difficult to operate accurately, therefore increasing the mobility, stability and precision, several smart materials, smart actuators and smart sensors are to be used to sense and react to the effect of environmental inputs, and to stimulate the devices. It is expected that these new type of smart flexible life saving robots will be able to solve the real world problems which are installed in industry, military, space, hospital, medical, surgical, home, echo friendly, inspection, public and security system for performing labour and life saving jobs. The smart materials are to be sense and react to the effect of environmental inputs and to stimulate the devices such as smart actuators and smart sensors which are basically very small version in size and light in weight. The actuators have to be developed from smart materials, such as Shape Memory Alloy and Electro Active Polymers which are very much suitable for the applications of life saving robots. The characteristics of these smart materials are that they have the ability to return to their original shape even after several deformations. One of the most commonly used shape memory alloy with a wide variety of applications in the field of biomedical is Nitinol, which is an alloy of two materials Nickel and Titanium. The main goals of Smart flexible life saving robots such as nano-robots/soft-robots/super-robots/swarm-robots/hap-tic-Interface-robots are as small as viruses, to cure the Cancer and protect other sophisticated parts of the human body.

KEYWORDS: smart materials / actuators / sensors, SMA, EAP, Smart flexible life saving robots, Nano-robots / Soft-robots / Super-robots / Swarm-robots / Hap-tic-interface robots

I. INTRODUCTION

The variety of micro intelligent sensors, open and closed loop real time control algorithms are used in smart flexible life saving robots. The wise variety electronic devices such as actuators, sensors, and controllers are to be used for optimizing the performance of various mechanical components of the selected systems. The micro-controller unit is put together around a central processing unit as the sensors such as displacement velocity and acceleration sensors are to be used for monitoring the selected system parameters. The signals from electronic smart sensors are to be amplified and converted into digital format by using interfacing electronic devices. There is a rapid growth in the use of smart materials, structures and systems in the current day engineering technology due to their advantages and intelligent features, because these materials that sense and react to the effect of environmental inputs and to stimulate the devices. Several smart materials such as shape memory alloys by *Nagarajan T, Molfino, Singaperumal M, Usha S et. al* [5,7,8,10] are finding increasing applications. The characteristic of these smart materials is that they have the ability to return to their original shape even after several deformations. The shape memory alloys are the metals that can be deformed and then returned to their original shape by heating. The most effective and widely used alloys include NiTi(Nickel-Titanium), CuZnAl, CuAlNi, NiTinol. Other elements can be added to the family of most important shape memory alloy-NiTi, because to improve its material properties such as ductility, high fatigue life and corrosion resistance. Nitinol is an excellent material for medical applications, because NiTinol by *Kim YS and Miyazaki S, Sreekumar M et.al* [6,9] are discussed and these smart materials possess a peculiar and unique constitutive behaviour, which strongly depends on the applied load and operating temperature. It exhibits typically two elastic behaviours when loaded up to failure. It has the ability to remember its initial shape even after subjected to several deformations and these materials restores to its original condition.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 3, Issue 5 , May 2016

The applications of smart materials cover areas such as automobile components discussed by *Westergaard* [3], telecommunications, aerospace, structures, robotics and medical field applications are discussed by *Prasanth KVSSD et.al* [11], planetary Exploration Control are discussed by Schilling K and Jungius C et. al[16]. Based on the survey of literature, it is found that actuators developed from smart materials, such as Shape Memory Alloy by by Sreekumar M, Muthuswamy S and zoppi et. al[1,2] and Electro-Active Polymers by by *Sait Usha et. al*[4], are very much suitable for spatial parallel manipulator applications. The response of SMA actuators mainly depends upon the way by which heat is added and removed. When high frequency actuation is required in spatial parallel manipulator, the actuator from piezoelectric material becomes very much suitable, but the strain produced is very low as compared to Shape Memory Alloy and Electro-Active Polymers.. It has the ability to remember its initial shape even after subjected to several deformations and these materials restores to its original condition. Haptic Interfaces for virtual environment, teleoperating systems, virtual reality and multimedia are discussed by Magnenat-Thalmann N and Bonanni U et. al[13] and Endo T et. al[12]. When high frequency actuation is required in nano-robots, the response of shape memory alloy actuators such as piezoelectric material becomes very much suitable, but the strain produced is very low as compared to and electro-active polymers.

II. SMART ACTUATOR

Smart Actuators such as SMA and EAP actuators were their simultaneous sensing and actuation capabilities. They have the ability to return to some previously defined shape and size when subjected to appropriate thermal action which is known as Shape Memory effect (SME). This distinguish characteristics include SME, large recoverable strains, high power density, high tensile strength, good damping properties, high thermal conductivity, good resistance, less sensitiveness to magnetic resonance, crush recoverability and excellent push ability. The properties these smart materials such as SMA and EAP actuators make appealing for both biomedical and nonmedical applications. The most common smart materials in SMA actuators are NiTi, NiTinol, NiTiCu are generally used in biomedical applications.

The advantages and limitations of SMA actuators are High power density means Large force output per unit weight, Large stroke length per Weight ratio, Large recoverable strain per stroke, Electrical actuation at small voltages, Rapid motion at a specified temperature, Easy to activate, High reliability, Verity of shape changes, Noise free operation, Biocompatibility, Compact and light weight, Insensitive to wide variety of environmental conditions. The unique characteristics of SMA actuators such as one-way shape memory, two-way shape memory and super elasticity make them suitable for a specific application. In general, for the use of SMA in spatial parallel manipulator applications, the important factors to be considered while designing a system actuated by SMA are the shape of the actuator, bias force required for deforming the actuator, type of fixing the actuator with the structure, type of control system to be implemented, heating and cooling technique need to be adopted for actuation and sensors being incorporated to measure the parameters like positions, temperature, force and resistance.

The one-way shape memory effect of smart material-Niti has soft, ductile and easily deformable in its lower temperature form with the application of an external force but it remains in the deformed shape even after removal of the external force. It resumes to its original shape and rigidity, only when heated to its higher temperature form. However it cannot reach the deformed shape once again after cooling. In, two-way shape memory effect the ability of SMA to recover a present shape upon heating above the transformation temperature and to return to the same shape upon cooling without the influence of any external force, means it is associated with a shape change upon heating and cooling without requiring any external bias force, and the super elasticity of SMA-NiTi has highly elastic, quite strong and hard.

The selection of a particular form of the actuator for a specific task is based on strain, bias force, actuation force or torque and frequency of operation. The thin film of Nitinol is another form of SMA actuator used in MEMS devices and medical applications such as in thin film Nitinol heart valve, thin film stent and contraceptive devices such as pump and valve. The various forms of SMA actuators for spatial parallel manipulators are linear actuators, spring actuators, rotary actuators, bundle actuators. The nonmedical applications of SMA are spatial parallel manipulators, automotive applications such as rear view mirror, thermal brake, clutch and on-off valve. The response of SMA actuators mainly depends upon the type of controllers incorporated and the way in which the heat is added and removed, which induce phase transformation. The generally applied heating techniques are conductive, convective, inductive heat transfer through microwaves or infrared light or direct ohm or joule or laser technique. A number of cooling techniques are like

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 3, Issue 5 , May 2016

water immersion, heat sinking, forced air or liquid cooling, still air or cools chips technique are available to reduce the cooling time of the actuator. The smart materials of electro-active polymer actuators are activated by electrically induced transport of ions, molecules and electrostatic forces developed due to electric field. The typical EAP materials are conductive, conjugated, piezoelectric ferroelectric, electro-strictive polymers, dielectric EAPs, carbon nano-tubes and nano-bots.

III. FUNCTION OF SMART ACTUATORS

The smart material that shrinks under electrical activation, consequently increasing in area on other directions of the device as shown in figure 1 and produce required tensile strain can be optimized for better activation effects. Such polymer actuators are fabricated with many thin layers of dielectric EAP films that are coated with silver electrodes. High strain can be produced with these actuators based on elastic stiffness and dielectric constants of EAP materials.

No voltage applied

Voltage applied

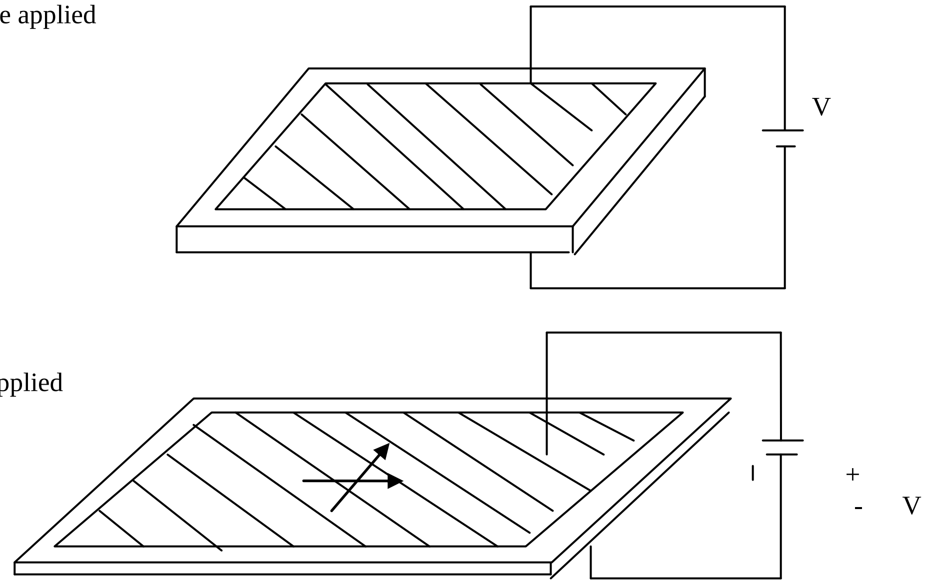


Figure 1: Function of Smart Actuators

The smart actuators works on the principal that opposite charges attract and like charges repel each other. The smart dielectric material is basically sandwiched between two complaint electrodes. When power is applied to smart dielectric EAP material, then stress is induced by electrostatic attraction, and this stress causes smart material to get compressed in the thickness and its area increases. The applications of dielectric EAP actuators are cardiac apparatus, energy harvesting and light weight speakers.

IV. SMART ACTUATORS FOR FLEXIBLE LIFE SAVING ROBOTS

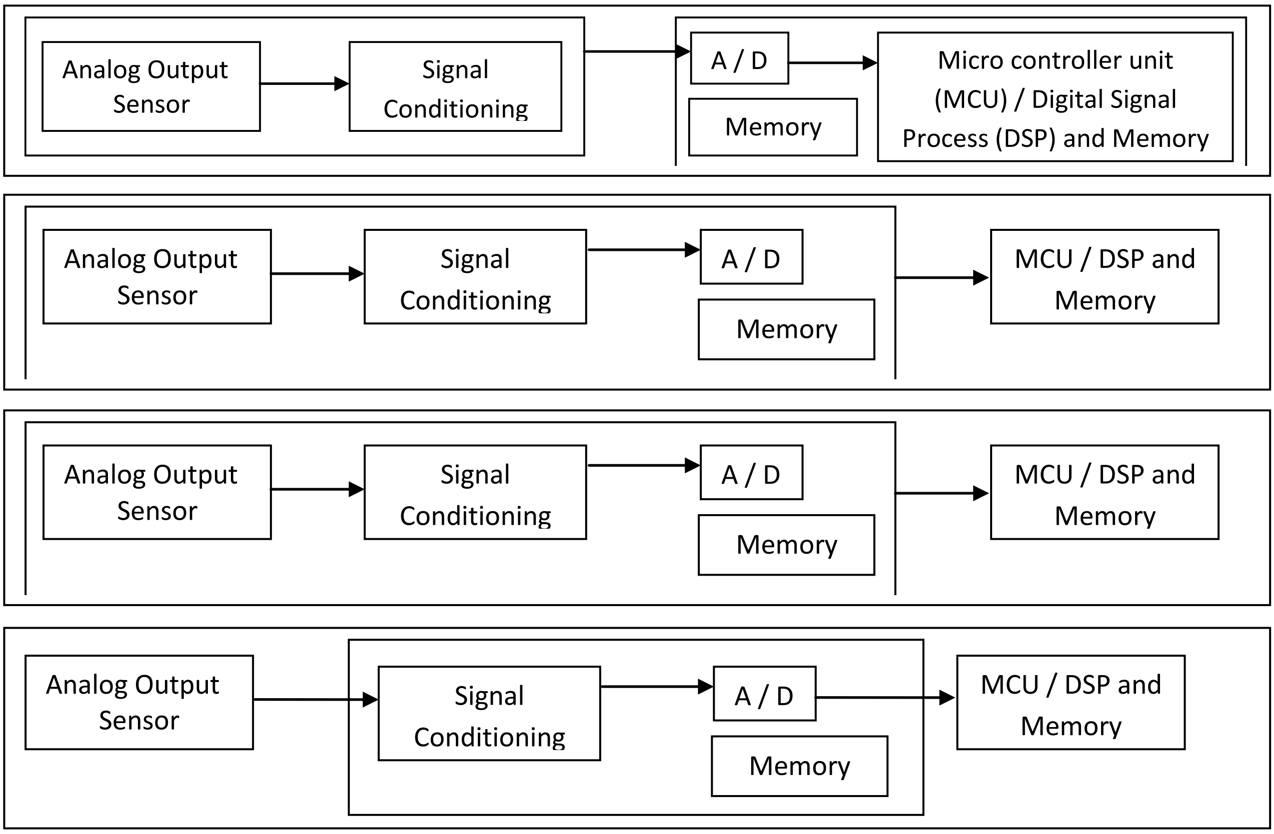
Smart actuators are invisible actuators with nanometre in resolution to achieve the required controllable displacements. The active nano-actuators are nano-magneto-strictive actuators, whereas semi-nano-active actuators are electro rheological and magneto rheological actuators. The shape memory alloy, piezoelectric and electro-active polymers are very much suitable for actuation and simultaneous sensing, the ability of smart materials are return to some previously defined shape and size when subjected to shape memory effect. The properties of shape memory alloy and electro-active polymers are large recoverable strains, high tensile strength, good damping properties, high thermal conductivity, good resistance, less sensitiveness to magnetic resonance, crush recoverability and excellent push ability. The most common smart materials in shape memory alloy actuators are NiTinol. The important factors to be considered while designing a system actuated by shape memory alloy are the shape of the nano-actuator, bias force required for deforming the actuator, type of fixing the actuator with the structure, type of control system to be adopted for actuation and nano-sensors being incorporated to measure the parameters like positions, velocity, acceleration, temperature, force and resistance. The selection of a particular form of the actuator for a specific task is based on strain, bias force,

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 3, Issue 5 , May 2016

actuation force, torque and frequency of operation. The actuators are fabricated with many thin layers of dielectric electro-active polymer films that are coated with silver electrodes. The strain produced with these actuators based on elastic stiffness and dielectric constants of electro-active polymer materials. The smart actuators works on the principal that opposite charges attract and like charges repel each other. The smart dielectric material is basically sandwiched between two complaint electrodes. When power is applied to smart dielectric electro-active polymer material, then stress is induced by electrostatic attraction, and this stress causes smart material to get compressed in the thickness and its area increases. The typical electro-active polymer materials are conductive, conjugated, piezoelectric ferroelectric, polymers and dielectric electro-active polymers.

These devices are used in variety of fields such as aerospace for high cycle fatigue test system, high bandwidth in actuator movement of flight simulation, missile fin positioning in aerospace, high frequency servo valves, tuning laser and seeker antennas, astronomy, optics and precision mechanism of sub-nanometre fabrication. The magneto-strictive actuators are made by magneto-strictive materials such as Terfenol-d which is an alloy of terbium, rare-earth dysprosium and iron. These devices are high stiffness in actuation and exhibit good linearity and a moderate level of hysteresis and used in noise free operations, biocompatibility, compact and light weight, insensitive to wide variety of environmental conditions. Shape memory alloys provide greater strains, good linearity, simplicity and having high hysteresis and effective for low frequency vibrations. Lever arm nano-actuator contain flexure hinged amplification mechanism, the nano-actuator sandwich a piezo- ceramic stack and caps of shallow cavities with amplification mechanism to convert the motion generated by the stack to a usable output motion in the transverse direction. The displacement output of the nano-actuator greatly increases with cavity diameter and depth which are used for proof mass actuation, micro positioning, active and passive vibration control system.

V. SMART SENSOR



ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 3, Issue 5 , May 2016

The inverse process of actuation makes the dielectric EAP material to work as the sensor. When force or pressure is applied on dielectric electro-active polymer, it changes its role and act as a sensor. The input force or pressure on smart dielectric EAP material, make its capacitance vary and the corresponding effect produces an equivalent electrical output in terms of current or voltage. The varies level of sensor integration with signal processing circuit as shown in figure 2. Varies Levels of Sensor integration with signal processing circuit The smart sensor offers a solution by integrating the sensor and necessary signal conditioning unit on a single package or on a single silicon wafer. The smart sensor is also posses signal processing capability and have a built in analog to digital converter, microcontroller and memory. The typical smart sensor functional block diagram is as shown in figure 3.

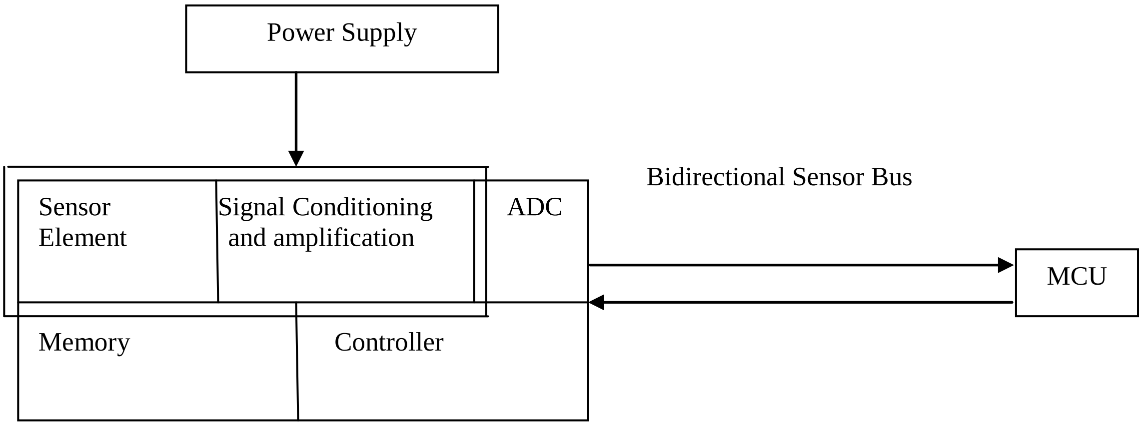


Figure 3: Smart Sensor's Functional Block Diagram

VI. SMART -SENSORS FOR FLEXIBLE LIFE SAVING ROBOTS

Smart nano-sensors are smart emitters and smart detectors which are made by smart nano-materials and present on inner walls of slot. They are used to calculate the incremental and decremented change in position and orientation of a vehicle by measuring the number of rotational speed of each of its wheel. The inverse process of actuation makes the smart dielectric, electro-active polymer material to work as the smart sensor. When force or pressure is applied on smart dielectric electro-active polymer, it changes its role and act as a sensor. The input force or pressure on smart dielectric electro-active polymer material, make its capacitance vary and the corresponding effect produces an equivalent electrical output in terms of current or voltage. The smart sensor offers a solution by integrating the sensor and necessary signal conditioning unit on a single package or on a single silicon wafer. The smart sensor is also posses signal processing capability and have a built in analog to digital converter, microcontroller and memory. Commonly used smart sensors are ultrasonic sensors, laser based sensors, infrared sensors, tactile sensors, vision based sensors and light based sensors which are called integrated smart sensors. These smart sensors emits high frequency sound signal and receives the echo signal from the obstacle for collision avoidance in mobile robots and used in design and development of circuits for distance measurement between a transmitter and receiver, and also used to determine the presence of target of an object rather than to measure the distance, these sensors works on the principle of flight of time.

VII SMART FLEXIBLE LIFE SAVING ROBOTS

A. Nano-Robots: The advanced technology of creating robots very near to the nanometre scale and constructed from the atomic molecular structure. The advanced researches on nano-robots/nano-bots/nanites have produced by the molecular structure of the complex system. The functioning nano-robot contains nano-sensors, nano-actuators, nano-synthetic molecular limbs, joints, bearings and motors. The nano-robots are as small as blood cells/Bactria/viruses which would perform the tasks on a tiny scale to cure the cancer, heart, lever, flu, sinus, neurotic problems and release the medicine in a particular place of the human body such as nano surgery on the level of individual cells and utility fog. Some more applications of nano-robots are manufacturing weaponry and cleaning.

B. Soft-Robots: Soft-robots contain deformable soft silicon bodies such as air muscles which are made by electro-active polymers, flexible actuators which are made by Ferro-fluids and are capable of different behaviours such as roll

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 3, Issue 5 , May 2016

and jump on a ground by the deformation of its deformable bodies which are controlled by using, fuzzy logic and neural network locomotion system.

C. Super-Robots: Some researchers have been investigating to creating super robots which can change their physical structure/ sophisticated shape to suit a particular task or situation like the unit of amoeba, which can move/roll/jump and change its configuration which depends on its requirement. That means these super-robots are self reconfigurable robots with variable morphology and that contain nano- autonomous kinematic mechanisms, nano-conventional actuators, nano-sensors, nano-controllers which are able to deliberately change their own shape by rearranging the connectivity of their parts and structure in order to adapt to new circumstances, perform new tasks and recover from facing problems. In these self reconfigurable robots the mechanism and its devices are capable of utilizing its own system of control such as with nano-actuators to change its overall structural shape by the process of set of modules can be added or removed to the system of super robot. The intent is finite nano-identical modules in a mesh of its nano-structure of self configurable super robot. The self reconfigurable robots allow a robot or group of robots to assemble and disassemble the components of nano-robots to form new morphologies that are better suitable for new tasks such as changing from a legged robot to a snake robot , rolling robot and then to a flying robot. . Since robot parts are interchangeable and self repair within a robot and between different robots and also replace faulty parts autonomously. The applications of these robots are envisioned space missions, space exploration and lunar colonization, rescue in mining, underwater exploration, self sustaining robotic ecology such as grow, heal of biological systems. The challenge key steps in the design of hardware, control algorithms are often intertwined. The design factors which are govern the limits on interface between modules, strength, and precision of robot components, power consumption and its efficiency. The challenges of control algorithms that determine the optimal configuration, time to complete a given task.

D. Swarm-Robots: The swarm-robots inspired by insects such as line follower of ants and bees which are exhibiting swarm intelligence and modelling the performance of behaviour task of tiny robots. The whole set of swarm robots can be considered as one single distributed system, which are finding something hidden, cleaning and spying. The swarms are like nanocentibots which are used for its collective behaviour and also more resistant to failure, a swarm can continue even if several robots fail and these swarm robots are suitable for space exploration missions.

E. Hap-Tic-Interface Robots: Hap-tic-interface robots are the specialized robots which are used in the design of virtual reality interfaces and allow touch enabled user interaction with real and virtual environments. These robots are simulating the mechanical and electrical properties of virtual objects which are used in robot rehabilitation process. Multi fingered hap-tic-interface robots are developed for the purpose of multipoint contact between users and a virtual environment, which have a higher potential and allow a user to make natural actions such as grasping, manipulation and exploration of virtual objects. A Hap- tic-interface consisting of an arm, fingertips and exoskeleton system of the virtual object which are used in large workspace and the nano-mechanism is mounted on the back of the virtual objects.

F. Locomotive Legged Robot: In locomotive legged robots set of point contacts are required between feet of robot and ground for sustaining the adaptability and manoeuvrability in rough terrain. The quality of the ground between those points and the robots are does not matter so long as the robot can maintain adequate ground clearance. The locomotive legged robots are potential to manipulate objects in the environment and capable of lifting and lowering the robots in several degrees of freedom. Locomotive legged robots focus on problems of traction and stability, manoeuvrability, and control velocity of the robot in desired cover space.

G. Space Lunar Robot: Space lunar manipulator system is mainly used for satellite development and construction of space stations at outside of the planetary exploration. There are challenging requirements for space lunar manipulators such as maintenance and repair of space stations, inspection of space vehicles, retrieve and exchange of equipment in space. The space shuttle of the planetary exploration is vacuum, extreme hot temperature or cold temperature or the operations are poorly known environment that mean dusty environment, radioactive materials and lower gravity.

VIII. CONCLUSIONS

The characteristics of these smart materials are that they have the ability to return to their original shape even after several deformations. One of the most commonly used shape memory alloy with a wide variety of applications is

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 3, Issue 5 , May 2016

Nitinol, which is an alloy of two materials Nickel and Titanium. It have a good material properties such as ductility, high fatigue life, corrosion resistance, light weight and easy to activate. The actuators have to be developed from smart materials, such as Shape Memory Alloy and Electro Active Polymers, are very much suitable for smart flexible life saving robots due to the development of large strain and actuation force. Nitinol is an excellent material for medical applications. This paper presents the benefits for using the smart materials in biomedical and nonmedical applications such as automobile, telecommunications, aerospace, structures, and medical field. The working principle along with a few applications of smart materials, efficient smart actuators, smart sensors and their performance characteristics, scaling laws, advantages and limitations are discussed in this paper to improve its accuracy, operational speed and flexibility in operation. The smart-actuators have to be developed from smart materials, such as shape memory alloy and electro active polymers are very much suitable for the design of nano-robots/soft-robots/super-robots/swarm-robots/hap-tic-interface robots and these sensors works on the principle of flight of time. These robots are as small as viruses, to cure the cancer and protect other sophisticated parts of the human body, used in nano-surgery. And also these smart flexible life saving robots are suitable for space exploration missions, design of virtual reality interfaces and exoskeleton system of the virtual object, space exploration missions, aerospace for high cycle fatigue test system and satellite development and construction of space stations at outside of the planetary exploration.

REFERENCES

1. Sreekumar M, “Modelling and Simulation of a Novel Shape Memory Alloy Actuated Compliant Parallel Manipulator”, J. of MES part C6, pp 1049-1059, 2008
2. Muthuswamy S and zoppi M, “Critical review of current trends in shape memory alloy actuators for intelligent robots”, J. of Industrial Robot Vol.34(4), pp 285-294, 2007
3. Caenen J,”Identification of geometric and non-geometric parameters of robots”, IEEE International conference on robotics and automation, pp. 1032-1037, 1990
4. Sait Usha, ‘‘Development of Dielectric Electroactive Polymer Actuator for Robotic Applications’’P. on ME Vol. 4(2), pp 180-187, 2011
5. Nagarajan T, ‘‘Design of shape memory alloy Actuated Compliant Smart Structure’’, J. of ASME Vol. 131/061008, 2009
6. Kim YS and Miyazaki S, ‘‘Fatigue Properties of TiNi shape memory Wires’’ Int. Con.of Shape Memory and Super elastic Technologies MIAS 473-478, 1997
7. Molfino, ‘‘Recent Advances in Nonlinear Control Technologies for Shape Memory Alloy Actuators’’ J. of SCIENCE A Vol.8(5), pp 818-829, 2007
8. Singaperumal M, ‘‘A genaralized analytical approach to the coupled effect of SMA actuation and elestica deflection’’ Smart Materials and Structures Vol.18/115026, 2009
9. Sreekumar M, ‘‘Application of Trained NiTi SMA Actuators in a Spatial compliant Mechanism’’ J. of Materials and Design, Elsevier Vol.30, pp 3020-3029, 2009
10. Usha S, ‘‘Elastic Behaviour of DEAP film in the Development of Actuators’’ J. of Procedia Engineering Vol.41, pp 1154-1161, 2012
11. Prasanth KVSSD, ‘‘Design of a New Biometric Flow Pump using SMA Actuators’’ J. of Applied Mechanics and Materials Vol. 110-116, pp 2903-2910, 2012
12. Endo T, “Five-fingered Haptic Interface Robot: HIRO III. Third Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems”, Salt Lake City, UT, USA, March 18-20, 2009
13. Magnenat-Thalmann N and Bonanni U, “Haptics in virtual reality and multimedia”, IEEE Multimedia, 13:6-11, 2006
14. Richard Lane and Benjamin Craig, “An Introduction to Smart Materials”, The advanced Materials and Processes Technology, vol.7, no.2, pp. 9-14, 2003
15. Young-Woo park and Do-Youn Kim, “Development of a magnetostrictive microactuator”, Journal of Magnetism and Magnetic Materials, pp. 272-276, 2004
16. Schilling K, Jungius C, “Mobile Robots for planetary Exploration Control Engg Practine, vol.4, pp. 513-524, 1996