The Division of Remote Handling & Robotics (DRHR) is engaged in developmental activities in a range of areas relating to reactivity control and in-service inspection of nuclear reactors at one end, to master-slave manipulators, industrial robots and mobile robots on the other. While master slave manipulators form the core of remote handling operations all over DAE, and are closely related to Robotics, they have been described at length earlier issues. In this article, we focus instead on the range of technologies under development using robot manipulators, mobile robots and other customized robotic devices for applications in automated material transfer, automated radiation survey, vision guided and force controlled manipulation, telepresence and surgery. We describe ongoing activities, occasionally hinting at future programmes that we wish to pursue in some of these areas.

**Automated Material Transfer System (AMTS)**

An Automated Guided Vehicle (AGV) based material transfer system has been developed, for automated transfer of materials between supply station, machining, and assembly units of a typical manufacturing setup. The same concept can also be used for automated transfer of radioactive materials from one point to another of a nuclear establishment (e.g., NFC, BRIT). Automated loading and unloading operations are performed by programmed motion of powered roller conveyors onboard the AGV, and on corresponding stationary units. Apart from the design and fabrication of the AGV (Fig. 1), the system includes development of various software modules for AGV motion control, position sensing (using laser navigator), and trajectory tracking (following pure pursuit algorithm). The possible routes for the AGV along with nominal speeds and stoppages can be specified in advance with a trajectory editor. A supervisory control program allows the operator to monitor status of AGV and conveyors, and intervene if necessary. He may also issue fresh commands for material transfers.

**Outdoor Mobile Robot with Onboard Slave Arm**

A Mobile robot with onboard slave arm, suitable for inspection and manipulation of a remote hazardous site is being developed (Fig. 2). It has four large wheels, each of which can be driven and steered independently. By suitably coordinating the speeds and angles of these wheels, the mobile robot...
can move along a straight line, turn on an arc, turn-in-place, and crab. The mobile robot will be teleoperated from a console equipped with a steering wheel and paddles for acceleration and brake. It has an onboard panoramic camera and display software to enhance situational awareness of the operator. The vehicle has an Attitude and Heading Reference System (AHRS) that consists of MEMS based Inertial Measurement Unit (IMU), integrated GPS and 3-axis digital compass to make it suitable for autonomous navigation in a pre-surveyed outdoor environment. This mobile robot can drive at a speed of 1 m/s on terrains such as pavement, grass, tar roads etc., and can negotiate a slope of 20% grade. A slave manipulator will be mounted on the vehicle. It will be teleoperated with a miniature master arm located at the control console.

In the near future, we wish to build wheeled and tracked platforms capable of negotiating stairs, curbs, ditches and rubbles. With an onboard foldable manipulator, this kind of robot can be compact and robust against shocks. Such robots may be gainfully deployed in anti-insurgency operations.

**Automated Radiation Monitoring using Mobile Robot**

Monitoring and mapping of radiation level, as well as locating sources of radiation are routine requirements in many areas of a nuclear installation. In order to reduce radioactivity exposure to the human operators, a small mobile robot equipped with onboard radiation detectors (1 R/hr to 2000 R/hr) has been developed, in collaboration with the Radiation Safety Systems Division (RSSD) of BARC (Fig. 3). This battery powered robot is equipped with a camera for driving remotely using radio communication from a Graphical User Interface (GUI) on a host computer. The GUI allows a user to build a radiation map of a contaminated area. It also helps in identifying the direction of source of radiation.

A variant of this robot is being constructed for monitoring from control room the gamma and neutron dose in vault areas during operation of superconducting cyclotron at VECC, Kolkata. In the future, we have plans to build an array of mobile robots for radiation survey in indoor as well as outdoor environments. For building radiation map over a wide area, coordination of multiple robots will also be necessary.

**Magnetic Climbing Robot**

Developed under an MoU with NTPC during July 2007 for inspection of boiler tubes, this robot comprises two sets of pulley-belt arrangement individually driven by two high-torque DC geared
motors, and uses Nd-Fe-B permanent magnets for adhesion while climbing onto the tubes (Fig. 4a). The robot is designed for various payloads by proper selection of size, numbers and arrangement of these magnets. The robot can be moved Up, Down, Left or Right by changing direction of the two motors used as above.

We have built a robot with a payload capacity of 9 kg and maximum linear speed of 120 mm/s. An ElectroMagnetic Acoustic Transducer (EMAT) sensor module, being non-coupliant inspection, is ideally suited for boiler tube inspection. The sensor module was integrated with the robot (Fig. 4b) and the system was field tested for tube thickness mapping at NTPC’s upcoming 500 MWe plant at Dadri during June 2009.

In future, we wish to install on-board, a camera for on-line visual inspection. Such magnetic climbing robots may find application in nuclear reactors as well. We intend to extend its application for dry/under-water cleaning of large size vessels having active fluid (e.g., Surge tank at Tarapur-1 &2; Active fluid built-up in nuclear waste reprocessing plants).

Vision Guided Robot Manipulation

In an unstructured environment, a robot can use vision to locate the object it is expected to handle. We have programmed a vision sensor interfaced to a KUKA KR-6 robot to identify, locate, pick and arrange randomly oriented PHWR fuel pellets from a table (Fig. 5). To achieve high accuracy in pick and place, the camera and robot were calibrated using customized grids. This will form part of a robot based automated fuel pellet inspection system being developed at DRHR in collaboration with RRCAT, Indore.

Remote Immersive Viewing

This project aims to develop a system for immersive viewing of a remote location. When deployed at the slave station of a Servo Manipulator, this
enhances the master operator’s ability to manipulate remotely. The system consists of a pair of cameras mounted parallel on a pan-Tilt-unit (PTU) and stationed at the remote (slave) site, and a Head Mounted Display (HMD) and a head-tracker installed on the master operator’s head. With signals from the head-tracker, the camera unit is made to follow the pitch and yaw motion of the operator’s head. Head-mounted system displays videos from left and right cameras of the slave environment in front of respective eyes of the operator. This creates the desired immersive experience - the operator feels as if he is present in the slave environment. Subsequently, parallel cameras were replaced with toed-in type camera arrangement to achieve better fusion of left and right eye images of objects close to the cameras. Other capturing and visualization techniques such as encoded video streams displayed on various types of stereoscopic and autostereoscopic display systems are also being designed and integrated under this project. A typical arrangement of remote immersive viewing system is indicated in Fig. 6.

In future, we wish to build a telepresence station for the master operator as an immersive interface to the remote slave environment. In addition to visual immersion, it will include stereo audio interface, as well as haptic interface through wearable exoskeleton as master, with cyberglove/cybergrasp to manipulate a robotic hand on the slave manipulator.

**Force Sensing and Control in Robot Manipulation**

For tasks in which a robot has to operate being in contact with external objects, it is necessary to sense the forces of interaction, so it can control its motion in a way that the task objective is achieved while keeping forces within their safety limits. A Schunk Force/Torque (F/T) sensor has been installed at the wrist of a KUKA KR-6 robot arm, and the robot programmed for some simple contour following operations (Fig. 7). Here the robot is asked to follow a certain trajectory exerting a constant force on the surface of the object. Otherwise, for following complex shapes in the absence of an F/T sensor, the programmer has to teach numerous intermediate points. Even then, if the path does not coincide exactly with the surface and dimensions of the part, it may damage the object or tooling. With the help of an F/T sensor, the robot can easily adapt its path over the complex contour of the object. This type of control has applications in robotic machining, finishing, deburring and polishing operations with axial or radial tools.
We have also programmed the robot for ‘lead by hand’, in which the robot is guided to a desired position, by applying a gentle pressure with hand. This makes it possible to move heavy loads with the help of a robot, without having to program it.

**Parallel Manipulators**

Parallel manipulators are a class of robots; their architecture and mechanisms give them very high rigidity and accuracy within a limited workspace. Various types of Parallel manipulators have been designed and developed. They can perform high precision manoeuvres and can handle payloads higher than their self-weight. Fig. 8 shows a three-degrees-of-freedom parallel manipulator developed in the division.

**Snake-Arm Robot**

Quite often, inspection needs to be carried out in inaccessible locations, such as the rear side of a cluster of pipes. No fixed-size manipulator can access all bends in such a constricted space. Only a Snake-arm robot may be able to access such a location. A Snake-arm robot is made up of a large number of independently controlled segments, so it can assume various shapes to suit the application. It can carry a payload ranging from 2kg to 20kg depending on the number of bends and the distance it has to cover. We have developed a prototype snake-arm robot having a total length of 1m (Fig. 10). A second version with a different mounting configuration is currently under development.

The snake-arm robot can be considered as a human spine comprising a number of vertebrae. Each segment is controlled by a set of wire ropes terminating at various points along the length of the snake. This permits control of each segment and thus the curvature and plane of curvature. Using a servo motor, the length of each wire rope is controlled independently. The control software calculates necessary lengths of all the wires to produce the desired shape. There are sixteen servo motors controlled simultaneously using a bus protocol. The software has many modes of

**Force-Torque Sensor (F-T Sensor)**

A jointless parallel mechanism based six-axis Force-Torque sensor has been developed, along with a DSP based signal conditioning, processing and communication system. It is designed to measure very small forces (1.5N) and moments (50N mm). Fig. 9 shows the F-T sensor acting as a working table while performing a robotic operation in association with a parallel robot.
operation. The user can use a joystick to drive the tip. This enables the snake arm to avoid obstacles and follow its tip into complex environments. Alternatively, the operator may specify the coordinates of the desired destination, and the tip of the snake will find its way or move on a programmed path to the desired point. For this, special servo drives and a front end GUI based application program have been developed. In an application, the snake-arm robot may typically carry a camera or a probe for inspection, a gripper for manipulation, or application specific tools for operation.

In a revised approach, a robotic arm performs the job of the assistant surgeon by positioning the laparoscope at the surgical site and holding it steady. The primary surgeon now manipulates the laparoscope using a foot-operated console. When the primary surgeon controls the laparoscope, it is more likely that it will be positioned to provide the best exposure for the job to be performed. Additionally, steadier camera positioning, fewer inadvertent movements will improve the performance significantly. The system is demonstrated successfully using an industrial robot available at DRHR. For convenience in clinical use, the robot is mounted on a small trolley as shown in Fig. 11.

Robotic Assistant for Laparoscopic Surgery

Laparoscopy or Minimally Invasive Surgery (MIS) allows surgeons to perform the same procedures as in traditional open surgery, using small incisions instead of large abdominal cuts. In such procedure, the surgeon monitors the surgical procedure by special video camera system (laparoscope) instead of looking directly at the organ being operated. There are significant benefits to the patient in terms of reduced post operative pain, reduced hospital stay and quicker return to normal physical activities. During MIS, both hands of the primary surgeon remain engaged in manipulating the surgical tools, while another surgeon (assistant) assists by holding the laparoscope focusing on the region of interest as commanded by the primary surgeon.
As an alternative and cost-effective solution, another system is also being developed. It has three degrees of freedom, and all the motions are decoupled. It can be mounted on the surgical table and can be powered from a small rechargeable battery. The basic operations were successfully demonstrated using the prototype shown in Fig. 12. Both the systems are planned to be thoroughly tested on animals at the Christian Medical College (CMC), Vellore, before using on humans.

The robotic system under development consists of three miniature (slave) arms - two for holding interchangeable modular surgical tools; the third one for manipulating the camera. The surgeon will sit comfortably at a remote console holding two master arms.

Programme in Autonomous Robotics at IIT Delhi

A programme, as a collection of projects in Autonomous Robotics, has been initiated at IIT Delhi, with support from the Board of Research in Nuclear Sciences (BRNS). The purpose is to involve the academia in technology developments in Robotics. The initial pool of projects relate to force controlled and vision-guided manipulation with robots, exploring alternative configurations for master slave manipulation with an industrial robot, developing telepresence solutions for immersive interface to a remote environment, as well as developing solutions for coordinated operation of multiple mobile robots. As we already have ongoing activities in these areas, we expect the programme to supplement our efforts through development of technically sound and refined approaches. Some of these solutions are aimed at meeting two basic challenges of inserting fuel pellets into clad – under program control, as well as through teleoperation using a telepresence interface.

Robotic System for Minimally Invasive Surgery

Although laparoscopic surgery has been a boon in many surgical procedures, the laparoscopic tools have limited dexterity, restricting the procedure to relatively simple operations. Also, these operations are quite demanding for the surgeons. As an alternative, a Surgeon can perform operations using miniature robotic arms in master-slave mode, sitting comfortably at a remote location. Robots are not to replace the surgeon, but to extend human skills. Improved 3D view of the surgical site, force reflection, tremor-filtration etc., can drastically improve the surgical performance. Similar devices are successfully being used in DAE for nuclear (hot-cell) applications. Miniaturization and some more improvements can make it suitable for medical applications.