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**Unmanned Ground Vehicles:
Present and Future**

From the Desk of Guest Editor



Dear Readers,

It is my privilege and pleasure to be the Guest Editor for this issue of Technology Focus, an important medium for dissemination of information and sharing of knowledge with the civil society. Unmanned Ground Vehicle (UGV) is a very critical technology of the future and it will have a very decisive role in all future conflicts. This issue highlights the design and development of various types of UGVs being carried out at CVRDE.

The legacy of CVRDE dates back to 1929 as a Central Inspectorate of Mechanical Transport Establishment at Chakalala (presently in Pakistan) and subsequently to the establishment as an independent laboratory at Avadi in 1975. Today, it has been transformed into a full-fledged premier establishment for the design and development of armoured combat vehicles for the Indian Army. To its credit, CVRDE has several success stories and many products have been inducted into the Services. Few of the products are: Armoured Patrol Car, Armoured Recovery Vehicle, 130 mm SP Gun on Vijayanta, Carrier Mortar Tracked and Carrier Command Post on BMP II, Bridge Layer Tank (BLT-72), Combat Improved Ajeya, Armoured Ambulance and Arjun Mk-I. CVRDE has also designed and developed Arjun Mk-II, Arjun Catapult, Arjun ARRV, etc. Further, CVRDE has also engaged in the design and development of Line Replaceable Units (LRUs) for LCA-Tejas and Rustom-II-Unmanned Aerial Vehicle (UAV). In line with the recent advances in the battlefield and as a proactive initiative, CVRDE has undertaken the design and development of UGVs. Designing and developing UGVs is a challenging task as it is a multi-disciplinary system-of-systems and involves a wide spectrum of diverse technologies, including mechanical, electro-mechanical, electro-optics, electronics, software, etc.

By its very nature, a UGV has to surmount many problems which are not faced by unmanned aerial vehicle or unmanned underwater vehicle, viz, the problem of navigation on unstructured and unpredictable terrains. Another important factor was that the UGV for military applications was an evolving field in India and there was very little information during the initial days of development, particularly for medium to heavy duty tracked vehicles.

It is a matter of pride that a series of UGVs and associated technologies have been developed by CVRDE within a short span of time. The major UGV development completed by CVRDE is the MUNTRA series of tracked UGVs. The three UGVs developed under this programme are configured for the three unmanned missions of Surveillance, NBC Reconnaissance and Mine Detection and Marking. The UGVs have successfully completed the rigorous validation trials conducted in summer/winter conditions at the Mahajan Field Firing Ranges (MFFR), Rajasthan. As part of the design and development of UGVs, methodologies and procedures for the integration and evaluation/validation of UGV systems/technologies have been evolved by CVRDE. Another major contribution of CVRDE is the development and nurturing of many industrial partners in this niche technological field; this has enabled our country to establish an indigenous source which can support further developments.

It is my sincere belief that this issue of 'Technology Focus' will provide an insight into the design and development of UGVs at CVRDE and will foster enhanced collaboration and sharing of knowledge among DRDO laboratories in this futuristic technological domain.

Jai Hind !

Dr P. Sivakumar
Distinguished Scientist and Director, CVRDE

Unmanned Ground Vehicles: Present and Future

Combat Vehicles Research and Development Establishment (CVRDE) is one of the premier research establishments under the Defence Research & Development Organisation (DRDO). It has its origin as Chief Inspectorate of Mechanical Transport Establishment (MTE), which was established in Chaklala (now in Pakistan) during World War II in 1929. After independence of India, this establishment was moved to Ahmednagar to form the Technical Development Establishment (TDE-Vehicles). It was later transformed into Vehicles Research & Development Establishment (VRDE), Ahmednagar.

In 1965, when a decision was taken to manufacture Vijayanta tanks in the country, the Heavy Vehicles Factory (HVF) was set up at Avadi, Chennai. To render R&D support to HVF, a detachment of VRDE was established as a nucleus at Avadi on 01 August 1965 and later it was made as an independent DRDO laboratory on 27 January 1969 with the name of 'VRDE, Avadi'. Subsequently, it was re-designated as CVRDE on 26 March 1975.

CVRDE is working with a mission 'design, develop and lead to production of tracked armoured vehicles and specialist vehicles to meet the needs of the Services and to build technological capabilities in critical areas including test and evaluation of combat systems'. This issue of *Technology Focus* gives an overview of the sustained efforts taken by CVRDE in the design, development, implementation and validation of UGVs and related technologies/systems during the period 2007 to 2017. This issue also outlines a road map for future developments.

Unmanned Ground Vehicles

A glance through the history of armed conflicts through the ages will reveal that fast adaptation and quick deployment of cutting edge technologies have always

enabled a fighting force to exert a decisive advantage over its adversaries in any conflict situation. This lesson is very relevant in today's rapidly changing battlefield scenarios, where countries having a technological advantage can dictate not only the outcome of an armed conflict, but can also make its presence felt in political, economic and other inter-related arenas. One such technology that is poised to dramatically alter the dynamics of the battlefield is the Unmanned Ground Vehicle (UGV). A UGV is essentially an evolution in combat technology that will have a large scale impact on the way future wars will be planned, fought and won.

The deployment of UGVs will not only protect trained human lives in dangerous battlefield situations but also a variety of potential UGV applications for military operations can significantly increase mission performance, enhance combat effectiveness, and ensure personnel safety. The deployment of UGVs enable stand-off operations and thereby reduce or remove operator risks in highly stressful and dangerous environments, such as active minefields and areas of explosives or Chemical, Biological, Radiological and Nuclear (CBRN) hazards. The diverse operational roles a UGV can perform include active combat roles, operations in dangerous or contaminated environments (mine fields and nuclear-biological-chemical-contaminated areas), disposal of Unexploded Ordnances (UXO) and Improvised Explosive Devices (IEDs), utility and logistic support roles, etc.

UGVs are increasingly being deployed globally for military and civil applications to enhance battlefield effectiveness, improve human safety and work as force multipliers. A recent US market report on Military Unmanned Ground Vehicles 2015-2025 predicts a very high potential for UGVs especially for Intelligence, Surveillance and Reconnaissance (ISR), Explosive Ordnance Disposal (EOD) and logistics domains. DRDO recognised the potential of the UGV during early 1990s and a few laboratories started developing UGVs aligned with their domain

expertise. Over the years, four different laboratories were identified for UGV development within DRDO, viz., Centre for Artificial Intelligence & Robotics (CAIR), Bengaluru, Combat Vehicles Research & Development Establishment (CVRDE), Chennai, Research & Development Establishment Engineers (R&DE(E)), Pune and Vehicle Research & Development Establishment (VRDE), Ahmednagar.

The categories of UGVs were classified predominantly on the basis of weight and traction: wheeled/tracked. Accordingly, all UGVs classified as micro/macro which weigh in the range of 5 kg to 50 kg are being developed by CAIR, those in the range of one to three ton by R&DE (E), wheeled vehicles up to five ton by VRDE and tracked vehicles beyond five ton by CVRDE.

CVRDE started the work in this multi-disciplinary UGV domain during 2007. Initially, tele-operation of a light weight all terrain tracked vehicle (Max Track IV) was developed. This was later scaled up by the development of a tele-operated modified BMP Nag Missile carrier (NAMICA).

Subsequently, CVRDE had taken up technology demonstrator project 'Conversion of BMP into Tele-operated and Autonomous vehicle', later named as Mission Unmanned Tracked (MUNTRA). A host of technologies like drive-by-wire, tele-operation, perception, robotic manipulators, autonomous navigation system (in association with CAIR), multi sensor data fusion, tele-operation of surveillance, NBC reconnaissance and mine detection payloads, open source software, power management, etc. were developed during this period. In addition, CVRDE was also one of the four labs actively involved in the development of a high speed UGV as an Indo-Singapore international collaboration project, tasked with development of vehicle actuation module for a Honda-CRV vehicle for both Phase I and Phase II of the collaboration.

In addition, CVRDE is carrying out a mission mode project for the conversion

of a tracked BD50 Dozer into a tele-operated Dozer for landslide and earth moving operations for the Indian Army in hazardous terrains. Plans are also afloat for the development of a Unmanned Combat Ground Vehicle (UCGV).

CVRDE has proved its technological capability while starting the project with practically no technical background in this demanding technological domain, to a matured level and that is the real challenge.

CVRDE has today developed the necessary expertise, experience and domain knowledge in this critical field and has achieved self-sufficiency. Today, CVRDE has the proven capability to convert any vehicle (wheeled or tracked) into rugged tele-operated or autonomous vehicles which can operate in demanding terrain or environmental conditions. The spectrum of UGV technologies and systems developed by CVRDE during the last few years is schematically shown in figure below:

Tele-operation of an All Terrain Vehicle

During the initial years, the development of a teleoperation of a

light weight All Terrain Vehicle (ATV) was taken up as a confidence building measure. The vehicle platform chosen was a tracked, skid steerable ATV, as the vehicle characteristics are similar to a full size tank. The main objectives were:

- ◇ Understand the technologies involved
- ◇ Understand the system performance parameters during teleoperation
- ◇ Study the correlation between the vehicle characteristics and the system performance parameters
- ◇ Evaluate the effect of system latency on teleoperation
- ◇ Evaluate the operator experience during teleoperation, with reference to the tele-presence provided by the perception system
- ◇ Understand and implement emergency response mechanisms

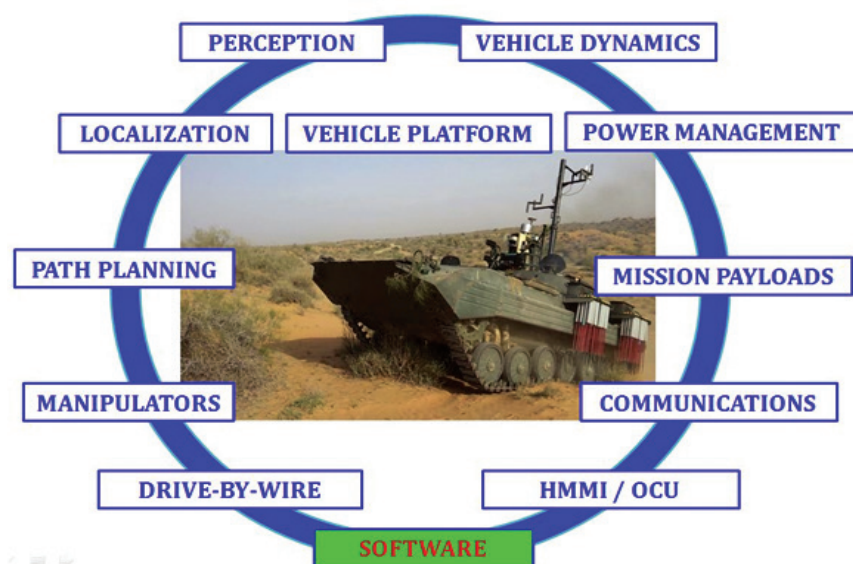
To ensure scalability and modularity, Commercial Off the Shelf (COTS) open source systems/items were predominantly used. The teleoperated ATV system has two major components: the teleoperated ATV (UGV) and the base station from

where the ATV is teleoperated. The work involved the design and development of all major systems of a full scale UGV, *albeit* on a smaller scale. The schematic breakup of the major systems in the Teleoperated ATV is as follows:

- ◇ ATV platform
- ◇ Drive-by-Wire (DBW) sub-system
- ◇ Tele-operation sub-system
- ◇ Base station sub-system

Drive-by-Wire Sub-system

This core UGV technology involves the conversion of the manually operated driver's controls (acceleration, brake, gear shift, steering, etc.), into electronically operated controls through the integration of electro-mechanical actuators, thus enabling the electronic control of the vehicle. The DBW system should also allow manual operation by the driver at any point in time. For the DBW system of this project, a stepper motor/drive and cable based mechanism was implemented for each of the driving controls of the vehicle. As the choke was to be operated for the starting of engine, a solenoid with spring return and a limit switch feedback arrangement was used to operate it. The



UGV technologies developed by CVRDE



UGV based on All Terrain Vehicle (ATV) and the base station

electronic starting was implemented using a series of relays to replicate the starter key positions. The accelerator control was implemented within the engine compartment using a stepper motor to directly actuate the throttle lever. Braking of the vehicle is done when both the steering levers are pulled back simultaneously.

Tele-operation Sub-system

Tele-operation is defined as the mode of navigating a UGV through wireless communication links, assisted only by the visual feedback received from the UGV. The controller hardware consists of a PC 104 based 800 MHz controller, with adequate Input-Output (IO) and ethernet port for control and data. It receives the commands from the base station and actuates the required driving controls of the UGV.

It is also interfaced to several sensors for vehicle health monitoring and control such as engine temperature sensor, ambient temperature sensor, fuel level sensor, etc. Warnings are issued to the base station operator whenever the engine temperature exceeds safe limit or when fuel level drops below recommended level. The perception system consists of two dome cameras, one in the front and one in the rear of the UGV.

Both the cameras have pan, tilt, zoom facilities, so that a satisfactory tele-presence effect can be given to the base station operator. For localisation, a GPS with 5 Hz update rate and 15 m (CEP) is used. One major requirement

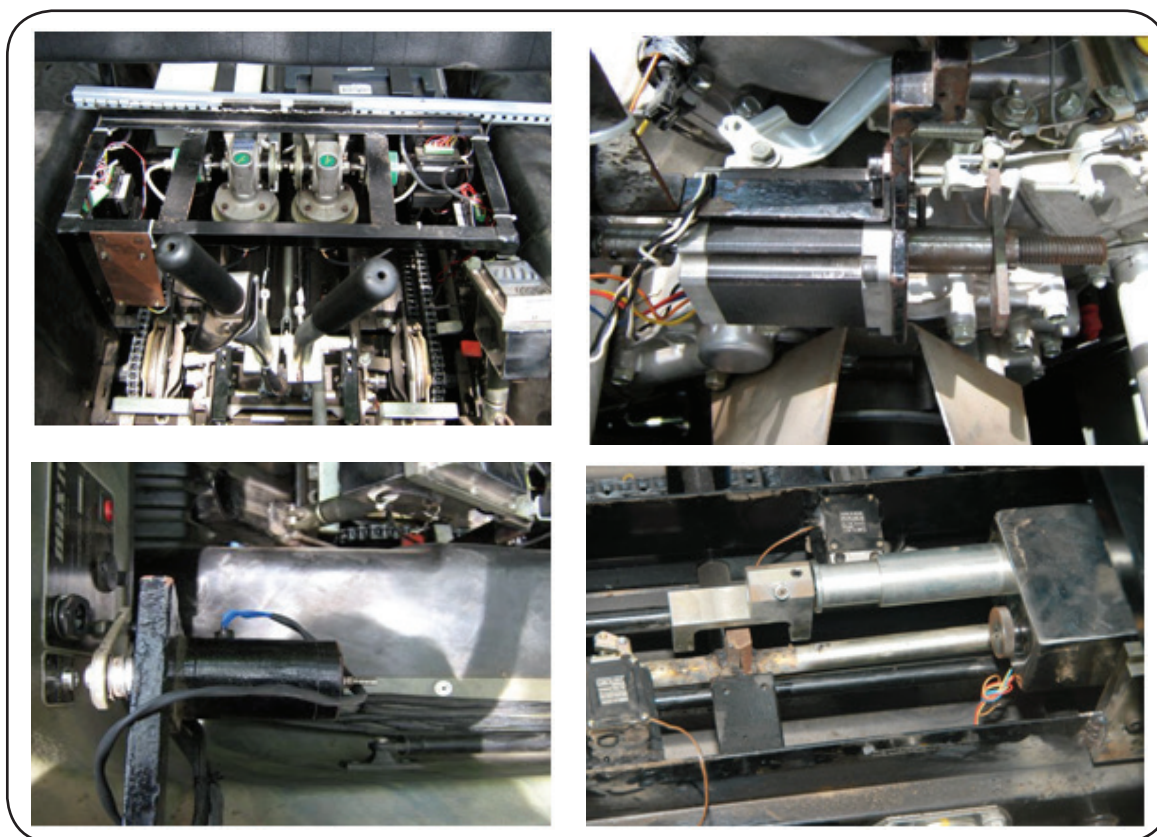
for any UGV is the automatic detection of obstacles on the path. For this project, the obstacle detection is implemented by two sets of ultrasonic sensors mounted on both the front and back of the UGV.

They are suitably angled to cover the entire width of the vehicle. If an obstacle is sensed by the obstacle detection sensors within three metre during teleoperation, a full brake command is automatically generated by the controller and the UGV is brought to an immediate stop.

The obstacles are also displayed on an obstacle map at the base station for the information of the operator. The power supply consists of two lead acid batteries.

Salient Features of the Drive-by-Wire System

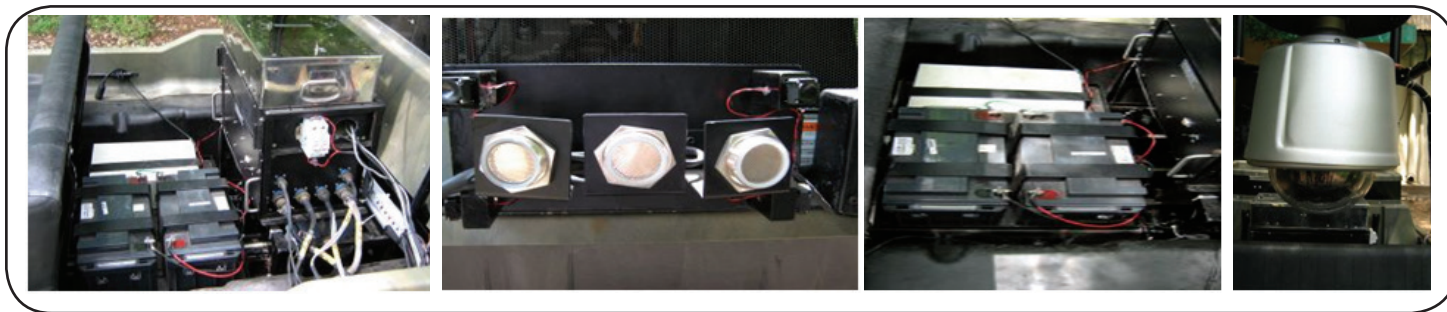
Accelerator	Stepper motor based drive actuator of throttle lever
Steering	Stepper motor/cable based actuation of the two steering levers
Brake	Stepper motor/cable based actuation of the two steering levers
Gear shift	Stepper motor/mechanical link based actuation of the gear link



The DBW system of the teleoperated ATV

Salient Features of the ATV Tele-operation System

Perception	Two PTZ dome cameras, one at the front and one at the rear of the UGV
	Resolution : 800 x 600 @ 25 fps
	Pan : $\pm 360^\circ$, Tilt : $\pm 90^\circ$, Zoom : x 30 (digital)
Obstacle detection	Two sets of long range and short range ultrasonic sensors
	Long range : 15 m, FOV 15° ; Short range : 6 m, FOV 90°
	Min distance to obstacle for automatic braking : 3 m
Communication links	Digital wireless links
	Frequency : ISM (2.4 GHz); Range : 5 km LOS
	No of links : 02; Throughput : 5 Mbps
Localisation	GPS; CEP : 5 m
	Update rate : 10 Hz
Power supply	Two 12 V, 75 Ah batteries
	Mission duration : 04 h
Vehicle health parameters	Fuel level, oil temperature, water temperature, battery voltage



Components of the tele-operation system of ATV

Base Station Sub-system

The base station is used to tele-operate all terrain UGV. It mainly consists of the operator console unit which includes a display unit and set of keys/switches/joysticks to generate the tele-operation commands for the UGV.

In addition to the display of the video received from the UGV, the display unit also presents the obstacle map, status of communication links, the vehicle health

parameters and all related information. The key board includes switches for the starting/stopping of the UGV, emergency stop button, headlights/horn, etc. The two rugged single axis joysticks are used to control the direction/speed and the steering of the UGV respectively.

The power supply consists of two lead acid batteries and a charger. All the components of the base station are integrated inside a wheeled cabinet having an internal 19" rack arrangement.

The all terrain UGV was successfully

validated by tele-operating it on various types of terrains. This initial work had enabled CVRDE to understand the technologies involved, system response characteristics and its effects on tele-operation and integration issues related to the development of tracked UGVs.

This project provided a strong technological foundation and gave confidence to take up further development of more complicated UGVs on heavier platforms.

Salient Features of the Base Station

Enclosure	Cabinet with 19" rack
Display	17" display
	Resolution: 1024 x 768 @ 30 fps
	GUI: Display of video, vehicle health parameters, obstacle map
Operator console	Two rugged, single-axis joy sticks
	Switches for power on, engine starting, camera control
	Emergency stop switch
	Status indicator LEDs
Communication links	Digital wireless links
	Frequency: ISM (2.4 GHz); Range: 5 km LOS
	No. of links: 02; Throughput: 5 Mbps
Power supply	Two 12 V, 75 Ah batteries with charger
	Mission duration : 04 h

being converted into an UGV.

CVRDE designed and developed all the major modules and sub-systems essential for converting this BMP-II based vehicle into a tele-operated UGV. The major sub-systems developed for this prototype are the DBW system, wireless communication system, video camera based perception system and an operator console unit.

The DBW module enables all the driver's controls such as brake, steering, acceleration, clutch, gear shifting, etc., to be controlled through Electro-Mechanical Actuators (EMA). The design and development of the DBW for this vehicle presented various challenges. This included different types of driving controls requiring higher forces for the actuation, issues related to actuation timing, integration and operation of some actuators within the engine compartment, restricted space availability in the driver's and engine compartment, etc.

As the vehicle was already near the end of its useful life, inherent difficulties



Base station for Tele-operated ATV

Tele-operation of BMP-II Prototype

After the successful completion of tele-operation of ATV, it was decided

to scale up the technology to a heavier class of tracked vehicle. Accordingly, a UGV prototype based on the BMP-II (NAMICA) tracked vehicle was decided to be developed. This was a challenging work, as this is the first time in India that a tracked vehicle of this weight class was



Prototype UGV based on Nag Missile Carrier (NAMICA)

related to the vehicle platform were also present.

The vehicle driving system was studied thoroughly by measuring the forces needed at the driver's controls of the vehicle. Based on these measurements, the EMAs for the accelerator pedal, brake pedal, clutch pedal, steering bar and gear shift were designed, developed and integrated in the vehicle.

The EMAs are based on BLDC motors with the required gear boxes and the mechanical linkages. Closed loop feedback was implemented to ensure accuracy of the final positioning of the driving controls. A dedicated NI based controller (with LabView programming) was used to control these EMAs.

Further, the driver's panel was also

instrumented to obtain key vehicle parameters such as fuel level, engine temperature, etc. which are displayed on the operator console unit.

The vision system consisted of four colour cameras, three in front and one at the back of the UGV.

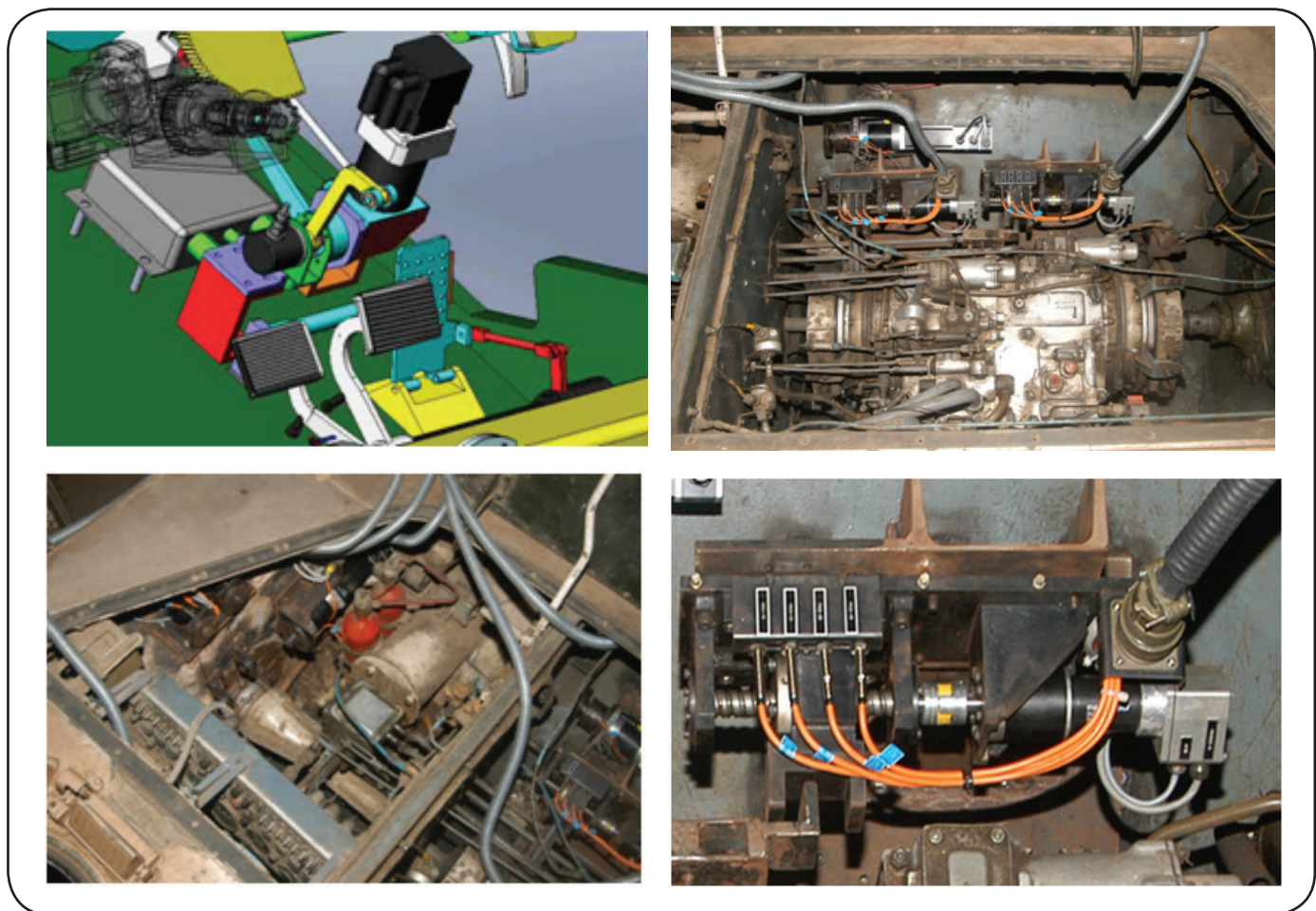
These cameras are essential to give visual information of the UGV's surroundings to the operator. These IP cameras route the video to the base station through an ethernet switch and communication radios.

The communication system consists of two wireless links, implemented using rugged radios. One is a low throughput link for the transfer of commands and data between the UGV and the operator console unit.

The other link has a higher throughput and is for the transfer of high resolution video from the UGV to the operator console unit. The operational range of both the communications links is five km Line-of-Sight (LOS).

The UGV is tele-operated from an ergonomically designed operator console unit. The unit replicates the look and feel of directly driving the NAMICA, with a set of driving controls and a dual screen display unit. One of the display screens display the video streamed from the UGV, while the other screen displays various vehicle health parameters. The operator console also has an attached retractable mast of height five meter, for mounting the communication antennae.

This work has enabled CVRDE to



DBW System in tele-operated BMP-II Prototype



Vision system in tele-operated NAMICA (BMP based)

generate the knowledge base and acquire the critical expertise for converting a medium tonnage tracked vehicle into a UGV.

In addition to the development of the relevant UGV technologies and systems, this project has enabled CVRDE to study and quantify the system dynamics, vehicle response characteristics and the inter-operability issues that invariably arises when a large tracked vehicle is converted into a UGV.

This work also enabled CVRDE to evolve guidelines for the testing and evaluation of UGV, including the safety related aspects.

Salient Features of the Tele-operated BMP-II Prototype (NAMICA)

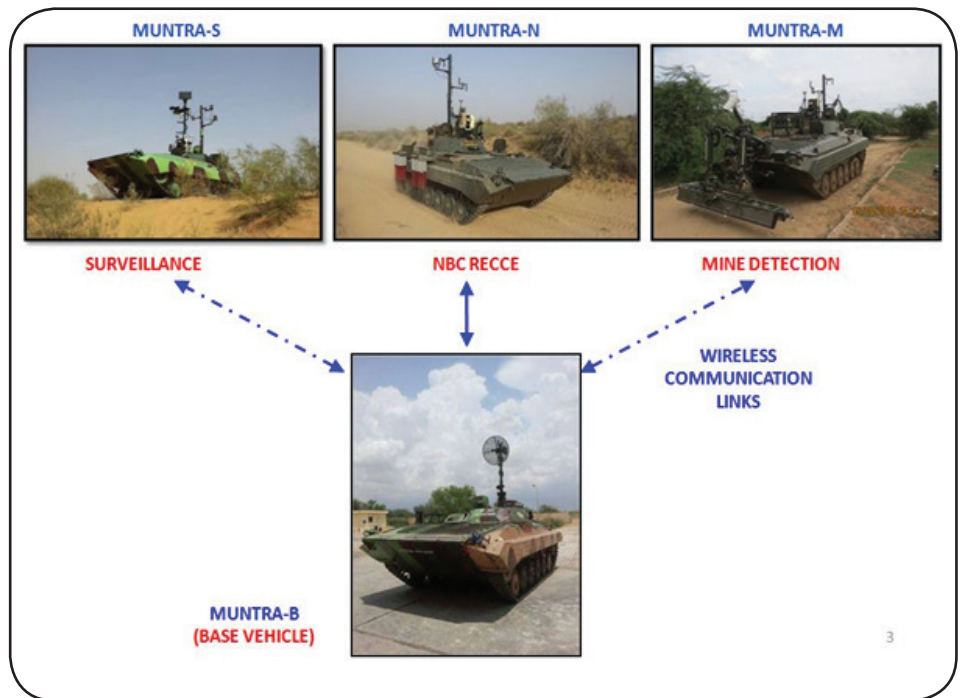
Type of vehicle	Tracked BMP-II
Type of control	Tele-operation and manual
Range of tele-operation	5 km (LOS)
Speed of UGV	15 km/h (limited due to safety requirements)
DBW system	EMAs for brake, accelerator, clutch, steering, gear shift and parking brake
Vision system	Four colour cameras
Communication system	Two wireless digital communication systems (for video and telemetry)
Base station	Twin display system, with operator control unit
Base station antenna	Omni-directional, on a 5 m retractable mast



Base station of the tele-operated BMP-II prototype

Project MUNTRA

CVRDE took up the prestigious UGV project 'Conversion of BMP-II into Tele-operated and Autonomous Vehicle' during 2007. The project was subsequently named as Mission UNmanned TRAcked (project "MUNTRA"). The objective of this project was to convert three BMP-II class of tracked amphibious vehicles into teleoperated/autonomous UGV platforms and to implement payloads for unmanned missions of surveillance, NBC reconnaissance and mine detection/markings missions. The system configuration consists of three UGVs (one for each of the payload missions) and one base vehicle. The developed UGVs are named as MUNTRA-S for unmanned surveillance missions, MUNTRA-N for unmanned NBC reconnaissance missions and MUNTRA-M for unmanned mine detection/markings missions. The base vehicle is MUNTRA-B, from which the UGVs are teleoperated through wireless communication links.



System configuration of the MUNTRA project



Base vehicle MUNTRA-B and its internal configuration

Salient Features of the MUNTRA-B (Base Vehicle)

Vehicle platform	Tracked, armoured amphibious BMP-II
Weight	11 ton
Engine power	300 hp
Deployability	All terrain, all weather, day and night
Mission duration	8 h
Operational configuration	Static during missions
Operational crew	Two (one for tele-operation for navigation and one for tele-operation of payload)
Tele-operation human machine interface	Operator controls for brake, accelerator, steering and parking brake
Tele-operation operator control unit	Left screen: GIS map and Obstacle map Middle screen : Real time video from the UGV Right screen (touch screen): Vehicle health parameters/virtual teleoperation controls
Obstacle map	Fused 2 ½ D map
Communication	Two digital wireless links for video and Cmd/Data
Communication mast	Electrically operated, telescopic and retractable, 8 m
Encryption	AES
Anti jamming	Yes (for Cmd/Data)
Antenna tracking	Automatic
Localisation	GPS (1.5 m CEP)
GIS	Indigenous IMGRS complaint GIS
Operator control unit for payload	Single screen console (modular and detachable)
Software framework	JAUS over Linux
Auxiliary power unit	4.5 kW, electronically controlled
Battery management	Through a Battery Health Management System (BHMS)
Compliant MIL Standards	Environmental : JSS 55555 / MIL STD 810E EMI/EMC : MIL STD 461E Ergonomics : MIL STD 1472D Power conditioning : MIL STD 1275D Documentation : IEEE 12207

CVRDE has developed a range of state-of-the-art UGV technologies, systems and integration/evaluation methodologies during this project. The intended terrain of deployment of the UGVs is the hot and dry desert terrains of the north western regions of country.

Base Vehicle

The base vehicle (MUNTRA-B) is a BMP-II platform to match the cross country performance of the UGVs. All the three UGVs (but currently one at a

time) are tele-operated from the base vehicle. The operation is planned in such a way that both the base vehicle and the UGV are driven manually to the point of deployment. Then the control of UGV is switched to tele-operated mode from the base vehicle and thereafter it is tele-operated by the operator from the base vehicle. Throughout the mission, the base vehicle is static and the UGV is mobile. To ensure that the communication link is always maintained, the antennae are mounted on a GPS based tracking system in the base vehicle.

Major Systems of MUNTRA UGV

Each of the three MUNTRA UGVs has a DBW and tele-operation system to enable mobility through teleoperation. In addition, each of the three UGVs has a specific payload to carry out its intended mission.

There are seven major systems in the MUNTRA UGVs. CVRDE has designed, developed, integrated and validated these seven major modules on the BMP-II vehicles to convert them into self contained UGV platforms.

Salient Features of the MUNTRA UGVs

Vehicle platform	Tracked, armoured amphibious BMP-II
Weight	11 ton
Engine power	300 hp
Deployability	All terrain, all weather, day and night
Mission duration	8 h
Operational configuration	Mobile, unmanned
Range of tele-operation	5 km LOS (extendable to 20 km LOS)
Speed of operation	Max 55 km/h (manual); Max 20 km/h (tele-operation, limited only by safety reasons)
Communications	Two digital wireless communication links (for video and Cmd/Data)
Encryption	AES
Anti jamming	Yes (for Cmd/Data)
Vision	Six CCD colour cameras (two on pan/tilt units); One thermal imager One stereo colour camera
Obstacle detection suite	Nodding 2D LIDAR, 3D LIDAR, MMW radar
Localisation	INS/GPS (tightly coupled. 1.5 m CEP)
Auxiliary power unit	4.5 kW, tele-operated from MUNTRA-B
Dynamic power control	Yes, through a teleoperated Power Distribution Junction Box (PDJB)
Software frame work	JAUS over Linux
Battery management	Through BHMS
Unmanned payloads	Surveillance (MUNTRA-S) NBC reconnaissance (MUNTRA-N) Mine Detection and Marking (MUNTRA-M)
Compliant MIL Standards	Environmental : JSS 55555 / MIL STD 810E EMI/EMC : MIL STD 461E Ergonomics : MIL STD 1472D Power conditioning : MIL STD 1275D Documentation : IEEE 12207

Drive-by-Wire

This core technology involves conversion of the manually operated driver's controls (acceleration, brake, steering, etc), into electronically operated controls, thus enabling tele-operation of the vehicle.

This technology is primarily the design of EMAs for each of the driver's controls, their integration within the driver/engine compartment of the BMP vehicle and the control through software. After the initial verification trials in CVRDE, this new technology was validated by tele-operating the MUNTRA-S during the summer field trials at Mahajan Field Firing Ranges (MFFR), Rajasthan during May 2012, where the temperature touched 52 °C.

Subsequently, the system was also integrated on two more BMP vehicles (MUNTRA-N and MUNTRA-M), which were also validated through field trials. Subsequently, the DBW systems in all the three UGVs were operated successfully during various summer/winter trials. This is the first trial evaluated DBW system developed in India for the BMP-II class of tracked vehicles.

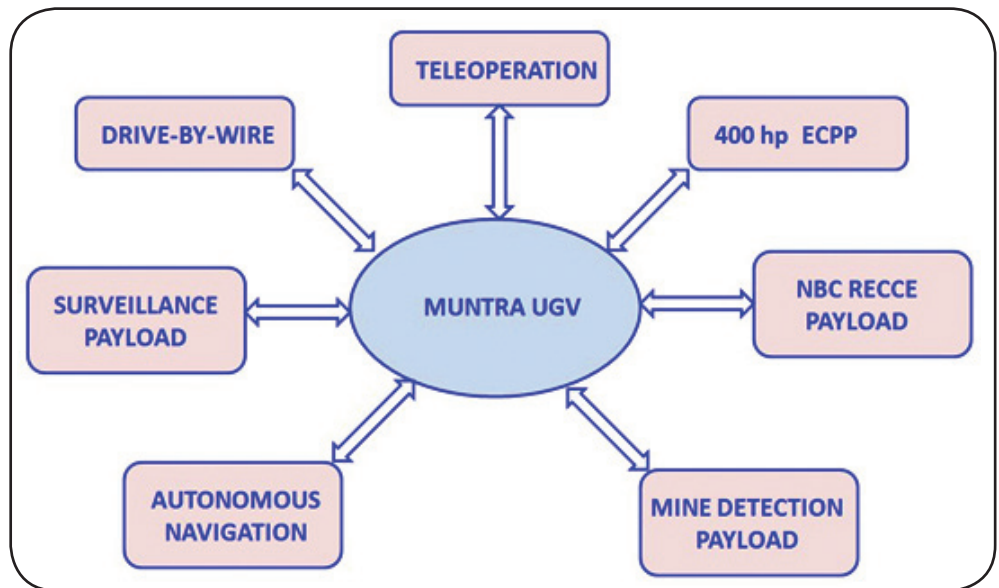
Tele-operation Module

The tele-operation system (along with DBW system) forms the core of UGV. During the project, various state-of-the-art technologies and sub-systems were designed and developed for the tele-operation system.

The tele-operation system was integrated in the BMP vehicles and was successfully validated during numerous summer/winter trials at MFFR during the period 2012-2014.

This is the first time in India that a UGV of this class was tele-operated under actual field conditions.

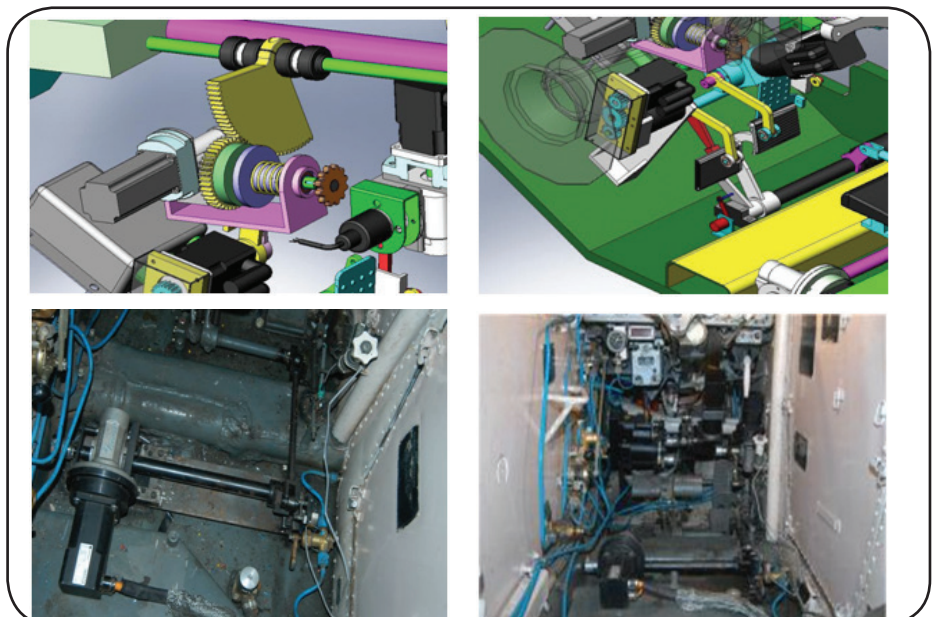
Modelling of DBW and its implementation in the BMP-II vehicle



Major systems of the MUNTRA UGV

Salient Features of the DBW System

Design	Indigenous, rugged, compact and reliable design
Electronic controls for	Brake, accelerator, steering, gear shift, parking brake
Software control	Complete control of the vehicle engine/transmission through indigenous software
Fail safe mechanism	Incorporation of an elaborate fail safe mechanism to ensure safety under all conditions
Mode change option	Quick interchange between tele-operation and manual driving modes
Software framework	JAUS over Linux



Salient Features of the Tele-operation System

Design	Indigenous, rugged, modular and scalable design
Communication system	5 km/20 km encrypted and anti-jamming digital wireless communication links with automatic antenna tracking
Vision system	Multiple (and switchable) CCD, thermal and stereo cameras for 360° vision
Obstacle Detection and Avoidance System (ODAS)	Multi-sensor suite of nodding 2D LIDAR, 3D LIDAR and MMW radar for detection of positive, negative and over hanging obstacles
Integrated power management system	BHMS, dynamically operated power distribution, teleoperated Auxiliary Power Unit (APU) and ultra capacitor
Operator console unit	Ergonomically integrated three screen display, associated switch/keyboards/driving controls
Augmented Reality (AR)	Enhancement of the telepresence using AR
Software framework	JAUS over Linux



Tele-operation system of MUNTRA

Surveillance Payload

This payload is integrated on the MUNTRA-S UGV and is meant to carry out unmanned surveillance operations. Ground and sea targets upto 18 km can be detected and tracked. MUNTRA-S is configured for unmanned surveillance missions using a suite of surveillance sensors, consisting of a Battlefield Surveillance Radar-Short Range (BFSR-SR) radar and an integrated electro-optics (with CCD/TI/LRF) mounted on a retractable carbon composite lightweight mast. Using this payload, a single operator can carry out the surveillance upto a range of 18 km under all weather, day/night conditions. The full range of the collected surveillance data is transmitted to the base vehicle, where it is displayed for the information of the operator. The innovative feature in the design is the automatic slaving of the electro-optics to the radar for the visual confirmation of the target detected by the radar. The surveillance payload was successfully validated during the field trials conducted at MFFR during the summer of 2012.



MUNTRA-S during trials at MFFR during 2012

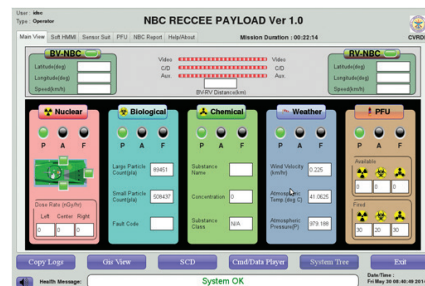
Salient Features of the Unmanned Surveillance System

Surveillance area	Elevation : + 15° to - 45°; Azimuth: n x ± 360°; Range: 60 m to 18 km
Operating conditions	All weather, day and night
Mounting	Any vehicle or stand alone
Surveillance in RF spectrum	BFSR-SR
Data from target	Range, speed, heading, lat/long size
Types of land targets	Crawling man, walking man, group of men, light and heavy vehicles, group of vehicles
Types of sea targets	Skiffs, small boats, small ships, large ships
Simultaneous detection	99 targets
Target classification	Manual and automatic
Surveillance in visual spectrum	CCD colour video camera, range 6 km
Surveillance in IR spectrum	Cooled thermal imager, range 4 km
Target ranging	Eye safe Laser Range Finder (LRF), range 10 km
Special feature	Inter lock of EO to radar EO, for visual confirmation of radar targets
Surveillance mast	Lightweight, telescopic, retractable mast, 8 m
Connectivity	Wireless/ethernet/FO
Software framework	JAUS over Linux

NBC Reconnaissance Payload

This payload is implemented on the MUNTRA-N UGV, which is meant for unmanned NBC reconnaissance operations. The NBC reconnaissance payload is mounted on the MUNTRA-N and is teleoperated from the base vehicle MUNTRA-B, and is intended to carry out unmanned reconnaissance missions in NBC contaminated areas. The primary NBC detectors are the nuclear radiation detector, a Chemical Warfare Agent/Toxic Industrial Chemical (CWA/TIC) detector and a Biological Agent (BA) detector.

The full range of the collected NBC data is transmitted to the base vehicle MUNTRA-B, where it is displayed for the information of the operator. The MUNTRA-N was successfully trial evaluated at MFFR during summer of 2014.



MUNTRA-N during desert trial at MFFR during 2014

Salient Features of Unmanned NBC Reconnaissance System	
Operating conditions	All weather, day/night
Detection of nuclear radiation	Gamma and high energy X-rays
Sectors of detection	Overlapping three sectors of 140°
Detection of CWA	G and H agents
Detection of TIC	A large and customisable library
Detection of BA	Bacteria, virus, spores and biological toxins
Biological agent size	0.7 μm to 10 μm
Measurement of weather parameters	Wind speed, wind direction, humidity, ambient air temperature and atmospheric pressure
Collection of soil samples	24 solid and 16 semi-solid samples
Collection of air sample	One sample
Picket firing device	Explosively fired colour coded steel pickets; (30 for N, 30 for C and 20 for B)
Software framework	JAUS over Linux

Mine Detection Payload

This payload is implemented on the MUNTRA-M UGV, which is meant for unmanned mine detection and marking missions. The primary mine detection sensor is the Ground Penetrating Radar (GPR) and the confirmation is given by the Vapor Detection System (VDS).

The GPR is mounted on two six-axis parallel manipulator arms and the VDS is carried by a five-axis manipulator arm. Once the mine is detected by the GPR, the vehicle is automatically stopped. Then, the mine will be confirmed by the deployment of the VDS.

Once the mine is confirmed, its location will be automatically marked by using paint spray as well as will be marked in the GUI in the base vehicle. The mine detection system can be tele-operated from the base vehicle MUNTRA-B or manually operated from MUNTRA-M. The deployment of the MUNTRA-M is also shown.

The processed GPR data is transmitted to the base vehicle for the visualisation of the mine by the base vehicle operator. This data includes information about the depth, size and position of the detected mine-like object.

The development of a real time

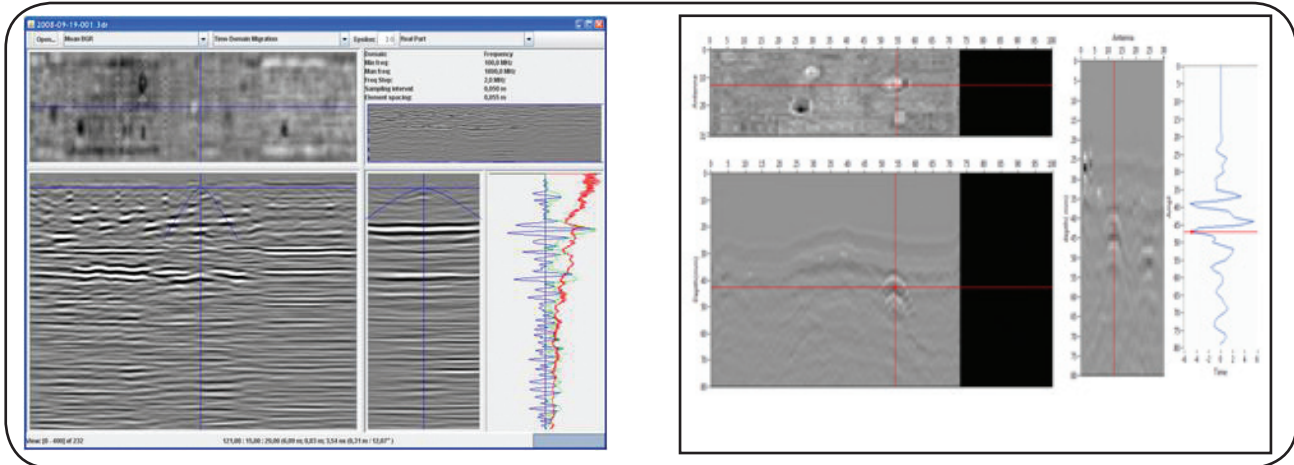
algorithm for detecting the buried mines within 200 ms while the vehicle is on the move and stopping the UGV on detection is a significant achievement by CVRDE.

The real time algorithm was developed

by combining many detection techniques like clutter removal, parabola estimation, feature extraction and classification, etc. The parabola estimation process is depicted in Fig.



MUNTRA-M during validation trials



Parabola estimation and noise removable process for detection of buried mine like objects

Salient Features of the Unmanned Mine Detection and Marking System

Operating conditions	All weather, day and night
Speed during mission	Upto 40 km/h (depends upon soil condition, depth and type of mines)
Vehicle stand-off distance	1.5 m
Primary detector	GPR
Type of mines detected	AP, AT and IEDs (metallic or non-metallic)
Depth of mines	Surface to 2 m (depends upon soil condition, depth and type of mines)
Deployment of GPR	Using a robotic manipulator arm of 6 DOF
Secondary sensor	VDS
Deployment of VDS	Using a robotic arm of 5 DOF
Marking of mine/IED	Spray of white paint
Software framework	J AUS over Linux

Autonomous Navigation Module

Autonomous Navigation System (ANS) is a cutting-edge technology for the autonomous navigation of vehicles. This module provides a limited autonomous navigation capability to the UGV. Based on a given sequence of GPS way points, the vehicle automatically navigates from the start location to the destination location by following all the defined GPS way points in between.

It also has the capability to detect and avoid obstacles in the path. The crux of the ANS is the path planning algorithms,

efficiency and execution speed. Thus two types of path planning are used in ANS: the global path planning and the local path planning.

The global path planning involves the generation of alternate paths between the GPS way points. The optimum path is then selected based on a cost map, which is essentially the degree of difficulty of each path.

The local path planning is used to avoid obstacles in the path and get the UGV back to the planned path. The detection of the obstacles is done using a sensor suite on the vehicle, consisting of 2D and 3D LIDARs.

The LIDARs give the location of the

obstacles with respect to the vehicle. Based on the size of the obstacle and the safe region defined around each obstacle, an alternate path is planned by the local path planning algorithm. Once the obstacle is avoided, the vehicle moves back into the pre-planned path given by the global path planner.

For the ANS, the software was developed by CAIR and the hardware was developed by CVRDE. The vehicle navigation commands (steering, accelerator, brake, etc.) was generated by the ANS software and forwarded to the DBW controller.

The DBW controller finally controls the vehicle driving system (steering,



Testing of Autonomous Navigation at MFFR

accelerator, brake, etc.) through a set of EMAs. The feedback from the DBW controller and from the localisation sensors is used for the closed loop control of the vehicle to ensure that it follows the specified GPS way points.

Various obstacle detection strategies and navigation algorithms were developed and implemented for the ANS module. Integration, testing and demonstration of the autonomous navigation system on MUNTRA-S were successfully completed in June 2014 at MFFR.

Electronically Controlled Powerpack

The existing BMP-II vehicle is fitted with a 300 hp (UTD-20) powerpack with manual transmission and steering system. For this UGV project, the interface to the engine was through the EMAs attached to the vehicle driving controls (steering, accelerator, brake, etc.). This introduces latency in the response of the UGV. To overcome this latency, a direct electronic interface to the engine/transmission is necessary.

Therefore, a 400 hp powerpack (engine and transmission) was specially designed and developed to meet this requirement of the MUNTRA project.

This Electronically Controlled Power Pack (ECPP) can be directly controlled

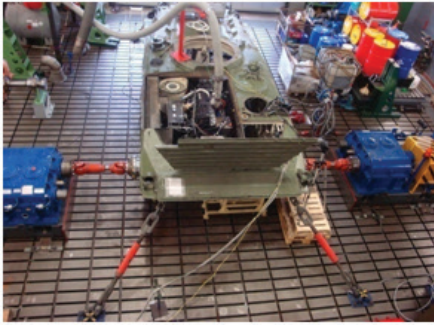
by appropriate electronic signals, without the intervening need for an electro-mechanical DBW system. Along with the 400 hp powerpack (with electronically controlled engine, automatic transmission and brake system) the required auxiliaries (*viz.* cooling system, air filtration system, etc.) were also developed.

All these systems have to be mounted within the existing engine compartment. The mobility criterion of the existing vehicle is to be retained in this upgraded system. The upgraded system is electronically interfaced by means of a Main Controller Unit (MCU) with engine control unit and transmission control unit. The systems interact with each other on a J1939 protocol wherein all control commands, system health checks, interlocks and diagnostics data are interfaced. The MCU interfaced with a telemetry system for wireless control of the powerpack. A GUI is provided for the operator to monitor and operate the system. A number of technical difficulties were overcome by CVRDE during the realisation of this powerpack. This is the first electronically controlled powerpack of this class in India.

The 400 hp ECPP was integrated in a BMP-II vehicle and was extensively field validated at MFFR during November-December 2015. During the successful field validation of the 400 hp ECPP, it was found the response and the handling characteristics of the vehicle were better as compared to a manually operated BMP-II vehicle.

Salient Features of the 400 hp Electronically Controlled Power Pack

Engine	
Make	Cummins
Engine power	394 hp @ 2100 rpm
Engine torque	1700 Nm @ 1350 rpm
Engine type	Inline 6 cylinder, 4 stroke
Cubic capacity	8.9 l
Idle speed	600-800 rpm
Transmission	
Make	Allison
Max gross input power	400 h
Gross input torque	1423 Nm
Input speed	2300 rpm
No of gears	4 forward and 2 reverse
Brakes	Multiple wet, oil cooled
PTO	60 kW
Torque convertor	TC-700



400 hp ECPP during integration and trials

Demonstration and User Field Trials

The MUNTRA-S and MUNTRA-B were demonstrated during the prestigious Defence Expo-2012 at New Delhi. Various dignitaries and other eminent visitors appreciated the concept and the implementation of UGVs. As a spin-off effort, in association with the Dte of LIC (DRDO HQ), a demonstration of the capabilities of MUNTRA-S and MUNTRA-M were given to the Central Armed Police Forces (CAPF) under the Ministry of Home Affairs (MHA) during

May 2015. The requirements of the CAPF/MHA in the domains of surveillance and mine/IED detection were discussed during the demonstration.

Based on the requirements of the CAPF/MHA, an extensive six months user trials were carried out by the MHA to assess the suitability of the Unmanned Surveillance System (USS) for coastal surveillance applications. This intensive user trial was conducted by the Central Industrial Security Force (CISF) at the Chennai Port Trust (ChPT) from 01 August 2016 to 30 January 2017. During the user trial, the USS was extensively

used by the CISF 24x7 for the surveillance of sea shore and sea based targets. Various targets on the sea were detected and tracked by the CISF upto a range of 18 km during this user trial. At the end of the trial, the MHA/CISF has stated that the USS is extremely useful for them and is very effective for surveillance of large areas with minimum manpower requirements. Based on the user requirements, CVRDE has also mounted the USS on a movable trolley for easy and quick deployment. Further follow-up is being taken up with the MHA through the Dte of LIC in this regard.



MUNTRA-S and MUNTRA-B at the Defence Expo-2012



Demonstration of MUNTRA-M and MUNTRA-S to CAPF/MHA



Demonstration of MUNTRA-M to MHA/CAPF



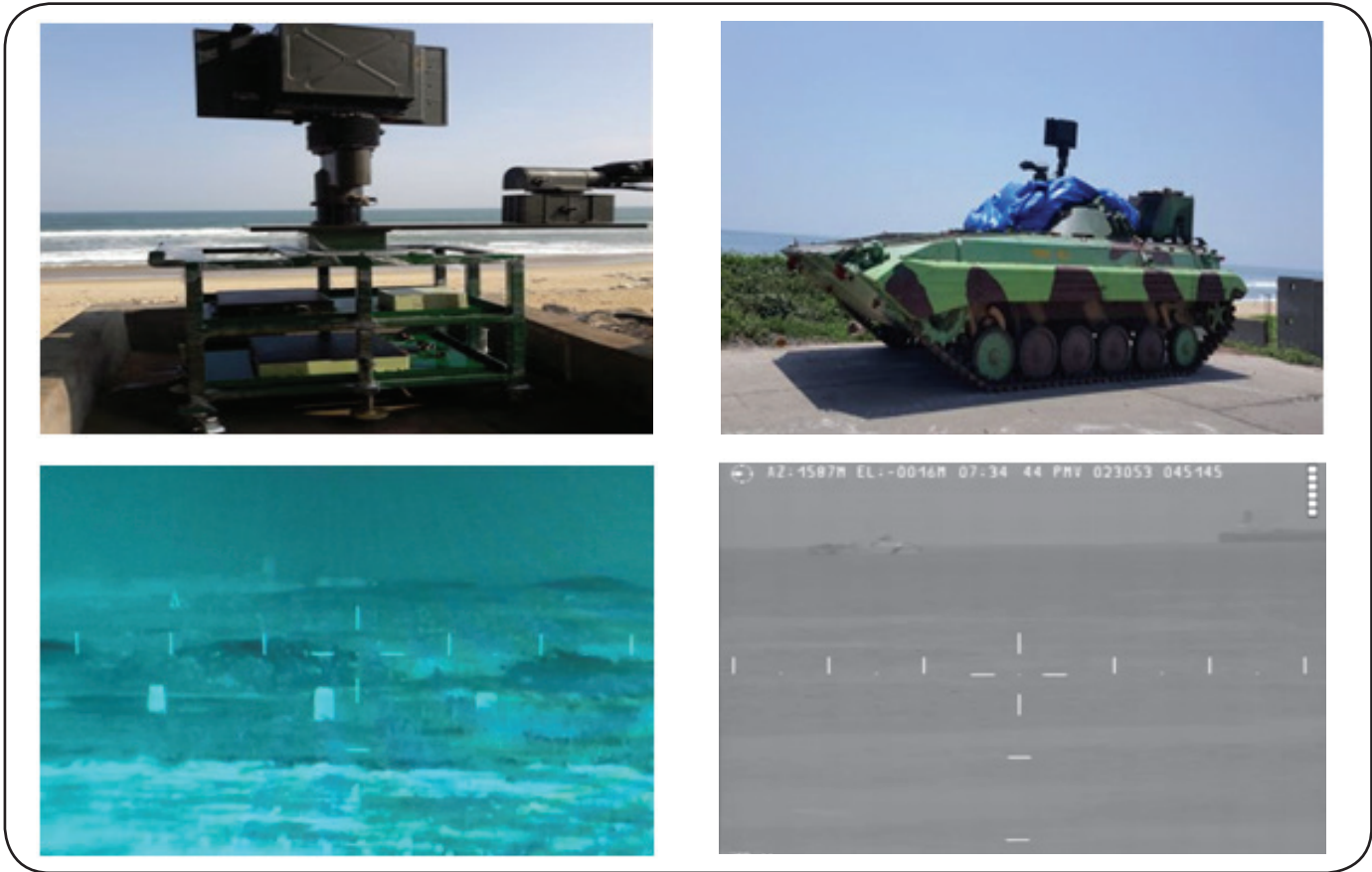
Demonstration of MUNTRA-S to MHA/CAPF



Deployment of MUNTRA-S for demo at Chennai Port Trust



Deployment of the surveillance sensor suite for coastal surveillance



Detection and tracking of various targets during the CISF user trials

International Collaboration for Development of Technologies for Autonomous UGV

India and Singapore entered into an international collaboration during 2006 to jointly establish the enabling technologies for Autonomous Unmanned Ground Vehicles (AUGV). DRDO and Defence Science & Technology Agency (DSTA) of Singapore are the collaborating agencies of the two countries.

The collaboration was carried out in two phases. In the first phase, both countries developed the enabling technologies for the tele-operation of a Honda CRV vehicle platform, viz., vehicle actuation module, operator's console unit and communication protocol. In the second phase which started in 2014, both the countries focused on establishing the necessary systems and modules for the autonomous navigation

of the SUV platform at high speeds. The improvements of the phase-I modules and the incorporation of a fail-safe module for more safety was also implemented during the second phase.

CVRDE has developed the Vehicle Actuation Module (VAM) for both Phase-I and Phase-II of the project. The VAM module consists of actuators for steering, brake, accelerator, parking brake and gear shifting and a motion controller. In Phase-I, the design of VAM was based on wire and pulley mechanism, with an electric motor driving the pulley and having a position feedback through an encoder.

The Phase-I demonstration was given to the Singapore team during 2010. In Phase-II, the design was radically

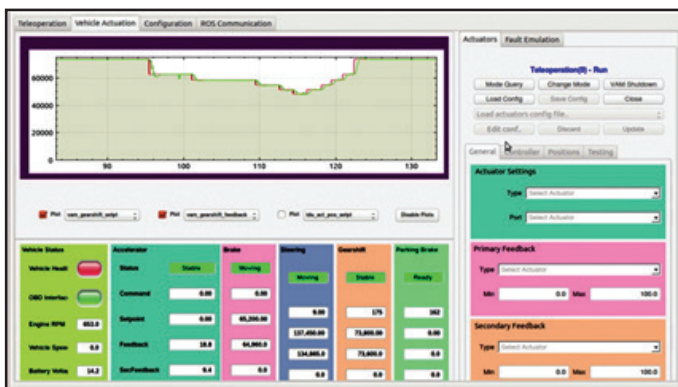
improved by CVRDE. The throttle EMA was eliminated by directly controlling the electronic throttle control of the engine through the ECU. The other controls such as brake and parking brake were realised using a push-pull cable mechanism driven by the BLDC motors.

The gear shift and steering were directly controlled through gears driven by a BLDC motor.

These improvements resulted in better control, handling characteristics and response time of the vehicle platform during tele-operation. Another additional improvement was the use of open source hardware and software resources. The tele-operation of the Honda CRV vehicle was successfully demonstrated by CVRDE during June 2017 at VRDE.

Salient Features of Phase-II Development by CVRDE

Vehicle platform	Honda CRV, automatic transmission
Speed of tele-operation	40 km/h
Driving controls for the vehicle	Accelerator, brake, clutch, gear shift, parking brake
Type of EMAs used	Direct voltage control
Accelerator control	Head lights, horn, parking lights
Discrete controls for the vehicle	Generic i5 based controller
VAM controller	ARM based embedded controller
Fail-safe controller	ROS on Linux (open source)
Software	ROS on Linux (open source)



VAM Integration and testing in the Honda CRV platform during Phase-II

To ensure the safe operating conditions of the UGV, CVRDE had also developed a Fail Safe Module (FSM), which detects a number of emergency/critical conditions and automatically takes appropriate actions.

The FSM was also successfully integrated and tested in the Honda CRV vehicle platform.

Tele-operated Dozer

In September 2017, CVRDE has undertaken a mission mode project for the development of a tele-operated BD50 Dozer, based on the specific requirements of the Indian Army. The objective is to save precious human lives during the landslide and snow clearance operations carried out by the Army at hazardous high altitude locations.

Salient Features of the Tele-operated BD50 Dozer	
Vehicle platform	BD50 Bulldozer of M/s BEML
Vehicle weight	10 ton
Engine power	90 hp
Operating conditions	All weather, day and night
Mission	Unmanned earth moving and snow clearance
Communication links	Two wireless communication links (for video and Cmd/Data)
Range of tele-operation	500 m LOS
Perception system	Colour cameras on pan/tilt platforms
Dozer driving control	Implemented through EMAs
Operator console	Portable handheld unit
Fail-safe mechanism	Yes, to ensure safety of the Dozer in narrow hilly terrains
Software framework	ROS over Linux



BD50 during snow clearance at Zojila Pass, Kashmir



Angling of dozer blade for snow clearance

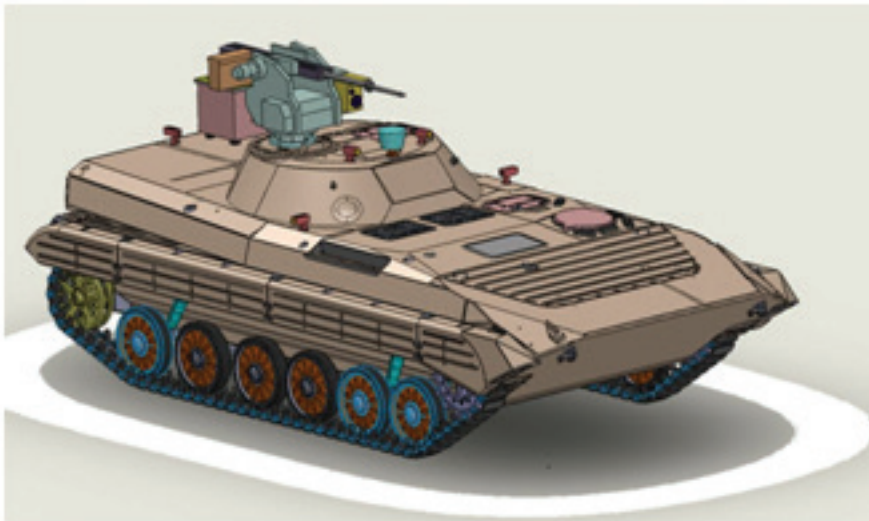
Future : Development of an Unmanned Combat Ground Vehicle

The Unmanned Combat Ground Vehicle (UCGV) is an unmanned ground vehicle with a suite of remotely operated weapons (current international conventions do not permit the use of autonomous weapons, even though the technology is readily available). The deployment of UCGVs will greatly enhance the battlefield effectiveness and

generate force-multiplier effects. It is projected that in the immediate future, the role of humans will be greatly reduced in the war front and the actual fighting will be done by UCGVs and similar machines.

As a proactive measure, CVRDE has drawn up future plans for the design and development of a tracked UCGV in a progressive manner through three

phases. The first two phases will develop a UCGV on the existing BMP-II tracked vehicles. The weapons systems shall include a Remote Controlled Weapons Station (RCWS), a soft kill Active Protection System (APS) and a medium power Directed Energy Weapon (DEW) system. A new high speed tracked vehicle platform shall be specifically developed



A conceptual model of the proposed UCGV

for the new UCGV in the third phase.

In addition to the RCWS with enhanced fire power, this new UCGV is expected to have a hard kill APS, high power DEW, SAMs, attitude control system and active camouflage.

UGV Roadmap for CVRDE

Though the current technologies are based on tele-operation and limited autonomy, the technologies developed by CVRDE can be extended further for the development of UGVs capable of undertaking more complex missions in dynamic and uncertain battlefield scenarios. Based on the future battlefield scenarios and the increasing pace of technological developments, it is projected that UGV technologies will move from the current tele-operated UGVs to fully autonomous network-centric UGVs by 2050. Accordingly, the UGV developments in CVRDE will also migrate to more evolved UGVs capable of complex missions in uncertain battlefield conditions.

The missions undertaken by the UGV will also shift from a passive logistics/support role to highly active weaponised combat missions. Combat UGVs will initially have only defensive capabilities, but will rapidly evolve into a potent platform for offensive military operations deep inside the enemy territory. The

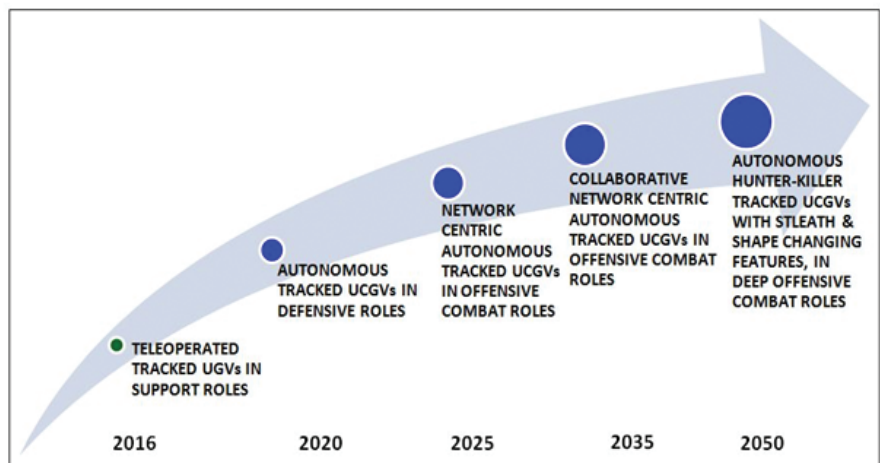
future road map for UGV developments in CVRDE is also shown. Significant spin-off developments for internal security applications will also be part of the roadmap.

Current systems use varying combinations of tele-operation and assisted autonomy for the systems to follow pre-defined routes, automatically detecting and avoiding obstacles along that route. Future UGV applications will require the development of more powerful technologies for autonomous navigation, starting in the near term with refinement of leader-follower

technologies completely autonomous operations in unstructured terrains and harsh environmental conditions. Also, advances in machine learning is essential to reduce the cognitive burden on operators, enhance efficiency of machine-human interactions, and enable more advanced operations, such as manned and unmanned teaming.

Other key technology focus areas include the enhancement of high-mobility and all-terrain attributes; continued development of power train and battery technologies to support increased endurance; navigation and timing technologies that do not rely on space-based signals; secure communications under NLOS conditions; automatic target classification, tracking and engagement; and operations in swarms.

As the future battles will be fought predominantly by unmanned or a by a composite collaborative teams of manned-unmanned systems, countries with technological competence in this very critical field will decide the outcome of all such future armed conflicts. Faced with potentially hostile situations both inside and outside our country ranging from a fully fledged war to low intensity conflicts, CVRDE/DRDO should rigorously pursue a long term plan for the development and deployment of UGVs to guard our borders and to make our country self-sufficient in this very critical technological domain.



CVRDE's road map for the development of UGVs



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