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nuclear engineering INTERNATIONAL

- Datafile: South Africa
- Steam generators
- Valves

Major parameters	Robot concept	…obot	Result of manufacture and test of demonstration robot
Main parameter			
Dimension	Width: 600mm Length: 1000mm Height: 1200-1800mm (variable)	Width: 715mm Length: 1270mm Height: 1610-1880mm (variable)	Width: 700mm Length: 1200mm Height: 1700-2000mm (variable)
Weight	500kg	700kg (excluding cable handling equipment)	700kg (excluding cable handling equipment)
Power consumption	Practical power consumption: p = several kW	In locomotion: approx. 14kW (at maximum leg speed) In work: approx. 13kW (with maximum load on manipulator)	In locomotion: approx. 8kW (at maximum leg speed) In work: approx. 8kW (with maximum load on manipulator)
Locomotion performance			
System	Quadruped, static walk system	Quadruped static walk system (with brake, articulation type)	Quadruped static walk system (articulation type
Locomotion speed (max)	Moveable at speed equivalent to man (4km/h)	Max. 300m/h (width: 1050mm)	Max. 214m/h
Minimum width of passage	General passage: 900mm Right-angled passage: 1000mm (60m/h)	General passage: 900mm (140m/h) Right-angled passage: 1000mm (60m/h)	General passage: 900mm (140m/h) Right-angled passage: 1000mm (60m/h)
Stepping up/down stairs	Steepest slope in facility: 45°	190H/230D (35°)	130H/230D (2-step over bridge)
Striding over	200Hm	200H/150D	200H/100D
Stooping through	1200H	1610H	1730H (32m/h)
Work functions	Works similar to man with conventional tools	Works similar to man with conventional tools	Works similar to man with conventional tools
Type	Two-arm multiple-finger manipulator	Two-arm, four-finger manipulator	Two-arm, four-finger manipulator
Load capacity	Power equivalent to man	20kg/two arms	10kg/two arms
Visual function			
Universal head (number of cameras)	Supply of visual information required for remote manual control and automatic control	7 degrees of freedom (5 cameras)	2 degrees of freedom (2 cameras)
System		Stereoscopic/ocellus, moveable	Stereoscopic
Communicaton function	Optical space system	Optical space system/optical fibre system (wide space/narrow equipment rooms)	Optical fibre system
System control function	A control system supported by autonomous control, with a high "sense at site" remote control system co-ordinating the visual sense/manipulator/locomotion mechanism etc.	A control system supported by autonomous control, with a high "sense at site" remote control system co-ordinating the visual sense/ manipulator/locomotion mechanism etc. Control mode: one-man manipulation Co-ordinated control of vision, legs, manipulator etc. Manipulator: master-slave control; multiple sense bilateral control; self-weight/friction inertia control; both arm co-ordinated control; autonomous/ remote co-ordinated control	A control system supported by autonomous control, with a high "sense at site" remote control system co-ordinating the visual sense/manipulator/ locomotion mechanism etc. Control mode: one-man manipulation Co-ordinated control of vision, legs, manipulator etc. Manipulator: master-slave control; multiple sense bilateral control; self-weight/friction inertia control; both arm co-ordinated control; partial autonomous/ remote co-ordinated control
High reliability	Function degeneration, health care, failure repair controller	Function degeneration, health care, failure care, failure repair controller	
Power supply	Self sufficient	External supply	External supply

were obtained for all component subsystems in terms of function and performance. But when overall system performance was examined, a distinct discrepancy was found between the robot workability and human workability. This is because no system can be built up simply by adding together component technologies. A total system can only be achieved when studies, adjustments and improvements are repeated to develop the right co-ordination between each component. System function and performance derive from the mutual interaction between component technologies. This clearly indicates the difficulties prevalent in system configuration.

However, while the achievements gained in this research project cannot be judged fairly by the function/performance of the final total system, various advanced robot technologies have indeed been taken a step towards the final realization of a mobile general-purpose work robot with high performance remote control capability. A clear direction has been established for future research.

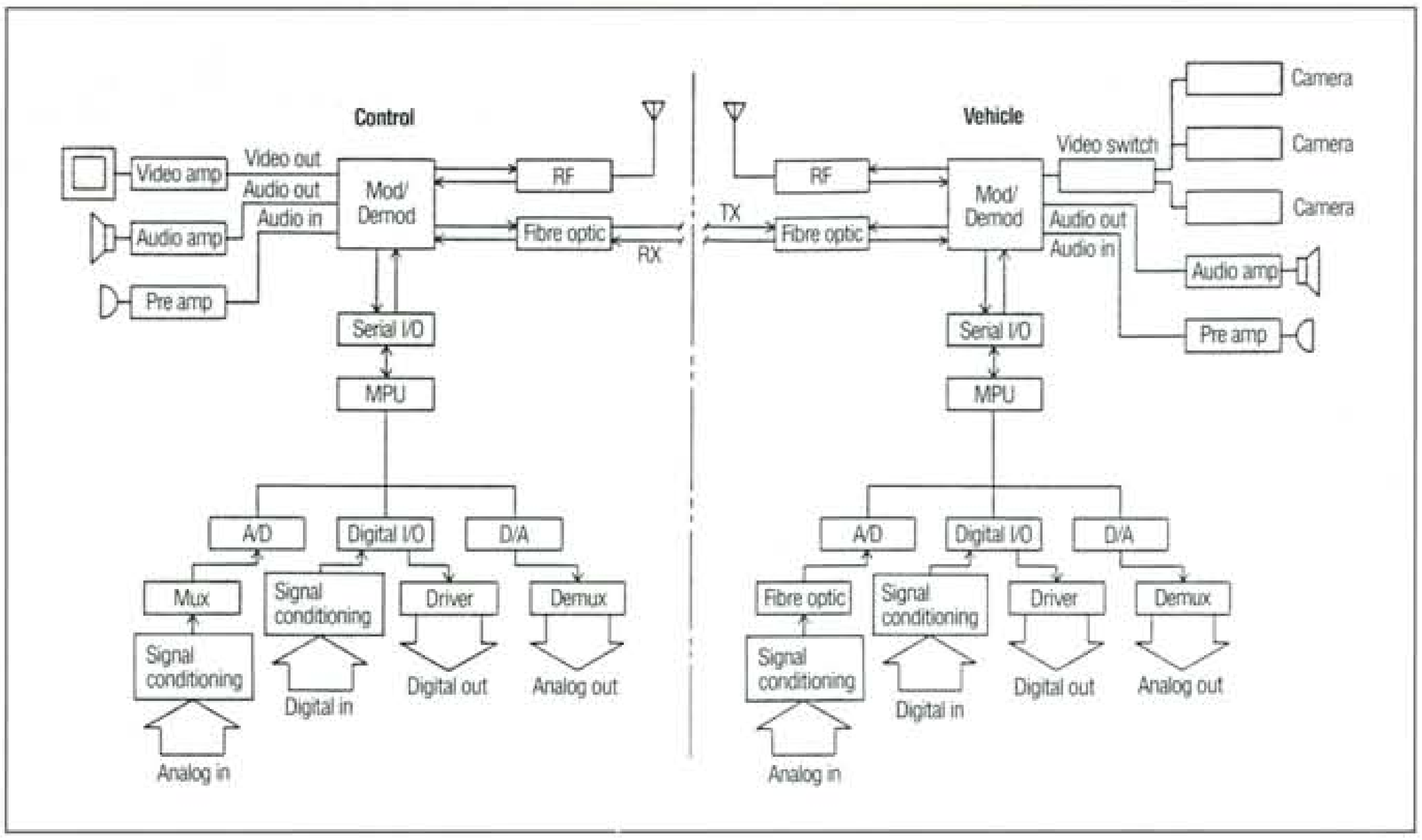
The final realization of highly-advanced robots is expected to come from the development of various small sensor technologies, control technologies for improved operability, the practical development of mechanics, and new light-weight components.

A remotely operated excavator

Force feedback enables a single operator to use the HAZ-TRAK remotely operated excavator with ease at nuclear waste sites and during decommissioning of nuclear facilities.

HAZ-TRAK is a remotely operated excavator and material handling system for nuclear waste site characterization, waste site remediation, and the decommissioning of nuclear facilities.

HAZ-TRAK combines the power and mobility of a commercial excavator, with the dexterity and controllability of a force feedback manipulator system: when operating HAZ-TRAK as an excavator, the operator can feel buried objects. A master/slave control method enables the operator to intuitively control all the excavator arm functions with one hand.



▲ **Block diagram of the HAZ-TRAK vehicle control system.**

The basic HAZ-TRAK system consists of a tracked vehicle excavator and a remote operator control console. HAZ-TRAK can be quickly mobilized and transported using commercial ground or air services.

THE VEHICLE

The HAZ-TRAK vehicle is a hydraulically powered, microprocessor-controlled machine. The vehicle is self contained with an on-board diesel power plant that supplies electrical and hydraulic power.

Locomotion is provided by two independently controllable hydraulic motors each driving a single track. The track drive provides traction with less than 4psi (2.8×10^{-3}kg/mm^2) ground pressure, allowing HAZ-TRAK to manoeuvre and work on soft ground. The fully tracked undercarriage provides a stable work platform and ensures stability while transporting loads.

When operating the system in confined spaces, counter-rotating track capability enables the vehicle to turn 360° about its own axis. Its versatility is further enhanced by a hydraulically actuated dozer blade which can be used for grading, backfilling and levelling the vehicle on sloped surfaces.

The excavating and material handling capabilities of the HAZ-TRAK system are provided by the articulated force feedback excavator arm. Basic excavator arm motion provides four degrees-of-freedom: shoulder azimuth (boom swing); shoulder elevation (boom elevation); elbow pivot (crowd or dipper); wrist pitch (bucket curl).

The vehicle cab and attached excavator arm can also be rotated through 360°. When HAZ-TRAK is used for barrel handling and other manipulative tasks, the excavator bucket may be replaced by a wide range of tooling. This includes end effectors which provide additional degrees-of-freedom.

HAZ-TRAK is equipped with a viewing system for remotely operating the vehicle and excavator arm. The basic viewing system includes two fixed colour cameras for peripheral vision, and a single pan and tilt mounted colour work camera with auto iris, auto focus and zoom. The high payload, hydraulically actuated pan and tilt unit can be configured with video and still cameras. Control electronics for vehicle, excavator arm, and viewing system operation are housed in an environmental enclosure in the vehicle cab. Modular design of the electronics simplifies installation and removal of equipment.

OPERATOR CONTROL CONSOLE

The operator control console incorporates controls and displays for remote operation and supervision of the vehicle system. The console is divided into three 19in (48cm) rack mount bays. All rack mounted equipment and major assemblies are integrated to produce a rugged, reliable operator station with an emphasis on human factors design.

The control console is designed to permit full system operation by a single person from the centre bay. High resolution 13in (33cm) colour monitors are mounted in the right, centre, and left bays of the console. The left and right side monitors are hinged and may be adjusted inward by the operator to provide an optimum viewing angle. The panoramic view afforded by these peripheral monitors greatly enhances operator awareness of the vehicle's surroundings. When more than one person is seated at the control console the side monitors may be adjusted outward to provide the proper viewing angle.

The centre bay of the control console features a two axis, fully proportional, displacement type joystick for control of vehicle speed and direction.

A trigger switch mounted in the joystick serves as a safety interlock that must be depressed by the operator to initiate any vehicle motion commands. A thumb operated switch on the joystick controls the dozer blade.

Panel mounted switches in the console provide control of: ignition (pre-heat/off/on/start); engine throttle (run/idle/stop); wiper (off/low/high); horn; driving light (on/off).

A small console mounted joystick also provides closed loop control of the camera pan and tilt unit.

Vehicle instrumentation and remote sensor data is displayed on the operator's television monitor. This information is continuously recorded on video tape recorders. Any monitor may be selected for this. Information which can be displayed and recorded, includes: fuel level; engine coolant temperature; engine oil pressure; engine RPM; alt/charge indicator; hydraulic system pressure; and (optional) cab rotate/azimuth indicator; inclinometer; and remote sensor data (customer specified).

The centre bay control console shelf, with joystick and panel mounted switches, is slide mounted and can be stowed beneath the centre console monitor during transport or when not in use. A lockable compartment in the centre bay provides additional storage space.

The left and right console bays contain 19in (48cm) rack mounted electronics, including: a Kraft model KMX 9000 vehicle telemetry system; a KMC 9100F force feedback control system for excavator arm operation; video switching equipment; and two VHS video cassette recorders. Additional rack mount space is provided for accessories. Pull-out drawers in the left and right bays provide storage space and a hinged writing surface.

FORCE FEEDBACK

The Kraft KMC 9100-MC hand controller is a compact, six degree-of-freedom, force reflecting master for bilateral control of the remote excavator arm. The master controller is kinematically similar to the human arm providing a comfortable man-machine interface with a high degree of dexterity and intuitive operating qualities.

Operating as a position controlled, closed-loop servo system, movements introduced at the master control arm by the operator are copied by the slave excavator arm. A fully intersecting wrist design reduces cross coupling and further enhances the operator interface. The controller is counterbalanced for effortless operation. When not in use, the master folds for storage.

Potentiometers at each of the six joints provide master positional information. Five axes are electrically actuated to impart force to the operator and automatically synchronize the master to the excavator arm at start-up. High force reflection and very low backdrive have been achieved through the development of custom electric actuators. Low force