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POWER AND SIGNAL TRANSMISSION FOR MOBILE TELEOPERATED SYSTEMS

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ABSTRACT

Appropriate means must be furnished for supplying power and for sending controlling commands to mobile teleoperated systems. Because a sizable number of possibilities are available for such applications, methods used in designing both the power and communications systems built into mobile vehicles that serve in radiological emergencies must be carefully selected. This paper describes a number of umbilical, on-board, and wireless systems used in transmitting power that are available for mobile teleoperator services. The pros and cons of selecting appropriate methods from a list of possible communication systems (wired, fiber optic, and radio frequency) are also examined. Moreover, hybrid systems combining wireless power transmissions with command-information signals are also possible.

INTRODUCTION

The design of a mobile teleoperated system must include some means of powering the vehicle and controlling its actions at the emergency site. For radiological accidents, the problems of supplying required energy and directions may become much more difficult because of possible extreme radiation exposures, the presence of corrosive gases, unpredictable excursions in ambient temperatures, and litter from damaged equipment.

All of these factors require careful considerations of the operational requirements and accident conditions an emergency teleoperated vehicle might have to manage and overcome. The judicious selection of a power supply and communications system should be based on these requirements.

Surveys indicate that there are a number of methods by which a mobile teleoperator might be powered and controlled. The purpose of this presentation is to bring to light some of these methods (including some that might be considered very "blue sky") for consideration in future conceptual/hardware designs. It is hoped that by presenting these possibilities a more open approach can be maintained when designing these interesting and important mobile emergency systems.

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POWER SOURCES FOR MOBILE TELEOPERATORS

Umbilical Systems

One means for supplying power to a remote vehicle is through a system of conductors that is continuously attached. Typical setups for accomplishing this are outlined below. (Figure 1)

Trailing Cables. All electrical power circuits are fed through a cable bundle which tracks behind the mobile device. This method is perhaps the most common and straightforward way to communicate power, but it may have serious problems from contamination in a radiologic emergency. Also, wire breakage inside a cable is possible due to cable flexing and binding when the device moves around corners. Typical cables for this service may range from 1/2 to 1 1/2 in. diameter and from 50 to 200 ft long. Cable weight may become a problem. Questions dealing with the payout and collection of such cables (e.g., contamination) must have design and operating solutions.

Coiled Cords. Helical-wound cables having built-in coiled spring tension capabilities may be partially or wholly suspended by supporting devices above the floor to avoid or reduce contamination and binding problems. These cables would still be susceptible to wire-breakage problems from repeated mechanical flexing and twisting.

Folded Cables. These conductors are usually supported by mechanical extenders of zig-zag shapes or by a sliding cable support. Although folded cables are held above the floor to avoid contamination, repeated flexing can produce conductor breaks.

Overhead Swivel Arm. In this arrangement, cables that provide power to the mobile unit feed down from an overhead arm that can swivel around in a full circle. A cable retractor could be used to maintain cable tension. Such an arm would be less susceptible to cable bending problems, but it would have to be preinstalled in the facility for possible use during emergency conditions. The arm usually requires a rotary electrical contractor at its turning center which adds problems relating to the operation of the contractor system. This configuration would be especially free from floor-borne contaminants.

On-Board Generation

The supply of power comes from a fueled-generator system. (Figure 2)

Organic Fuel in Tank. An engine-driven generator can supply power to the remote device. It may have attending safety problems from fuel storage and/or from exhaust sparks or fumes. It has the advantage of being a fairly powerful

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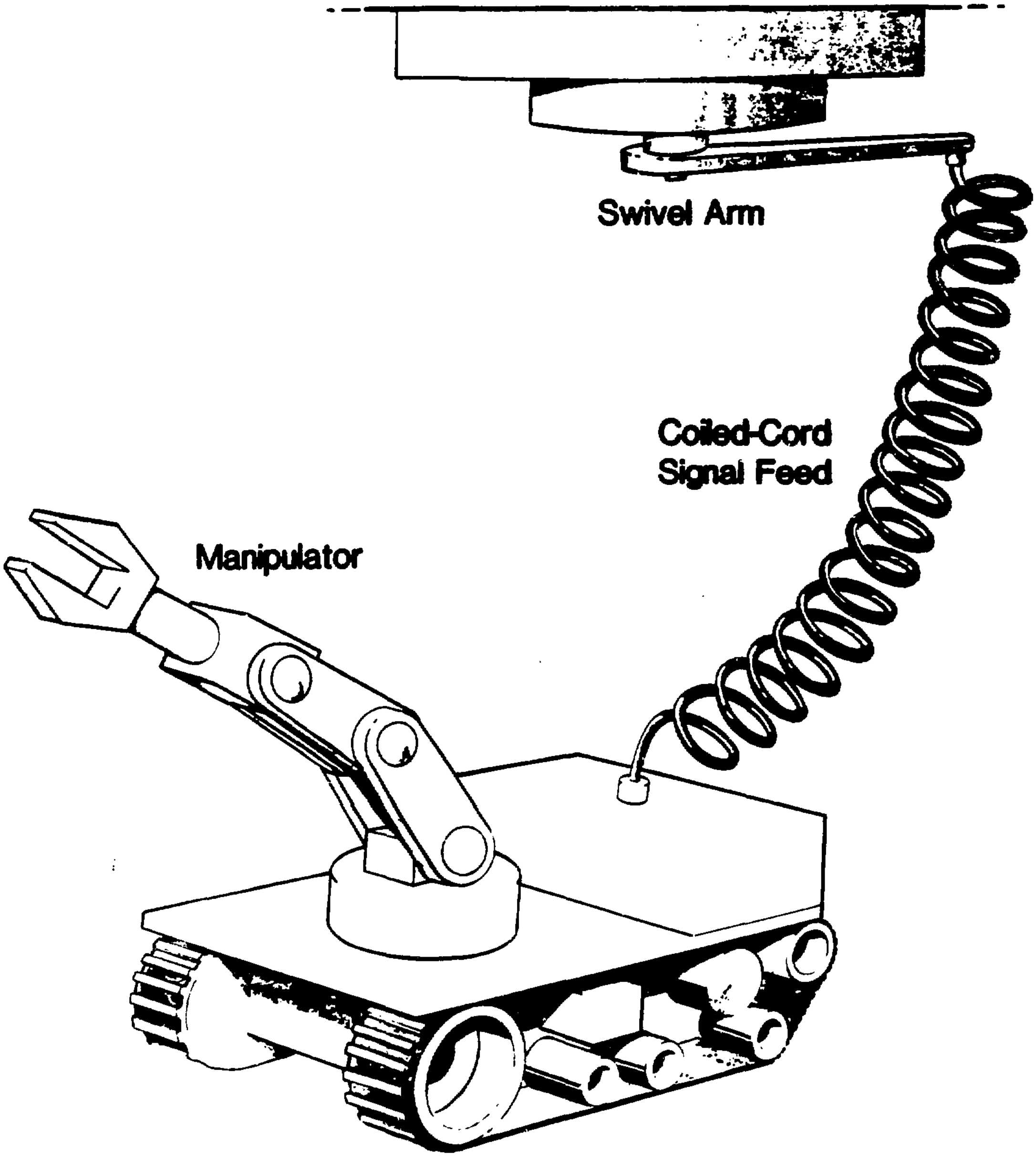

Figure 1. Mobile Vehicle with Coiled-Cord Umbilical Plus Swivel-Arm Feed for Command Signals

source of energy (i.e., high power-to-weight ratio) that is self-contained for mobile operations.

Compressed or Liquified Gas. This would operate using an on-board generator or fuel cell. Like the organic fuel model, this also may have safety and exhaust problems and may possibly release unsafe gaseous fuel through an accidental tank rupture.

ENERGY STORAGE SOURCES

These vehicles rely on stored on-board power. (Figure 3)

Lead-Acid Batteries

This battery-powered unit would have the advantages of being commonly available on the marketplace, and having a fairly high power density per unit volume. Problems arise from its weight, potential acid spills, and hydrogen-release characteristics. It must be constantly trickle charged to maintain readiness. Power storage capabilities of about 600 Wh/ft^3 are typical.

NiCad Batteries

NiCad batteries have somewhat higher energy density per unit volume than lead-acid types (750 Wh/ft^3 typical), and have longer charge-storage lives before needing recharging. However, comparable NiCad batteries are considerably higher in initial cost, and they have a "memory" characteristic that requires periodic deep discharge followed by complete recharging cycle to maintain cell-life capabilities.

Direct Drive from Compressed or Liquid Gas

The working gas would directly drive the teleoperator vehicle's actions and manipulator functions through pneumatic actuators. Direct drive would avoid energy-expensive conversions. (Mechanical-electrical conversion efficiencies are typically low.)

Direct Drive from Mechanically-Stored Energy

Large industrial springs or flywheel devices can store considerable amounts of motive energy that could be directed to drive vehicle and manipulator actuators through escapements, transmissions, and electrical clutches. Low-speed operations can be very energy efficient. (The plug-in rewinding of springs could be investigated as a means of renewing the stored energy.)

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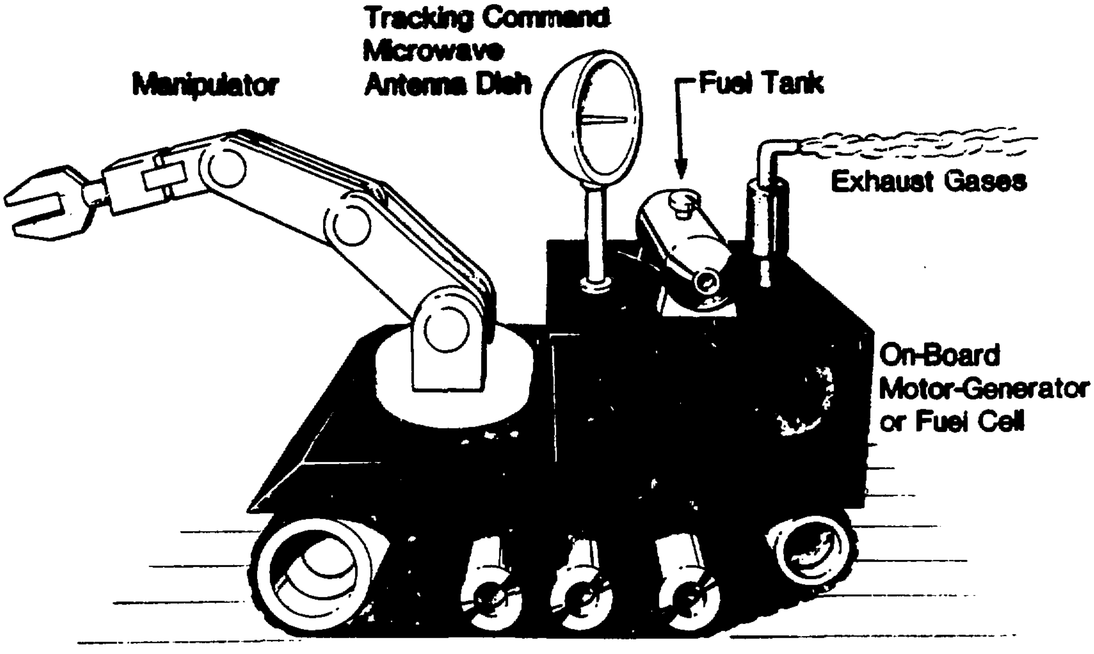

Figure 2. Teleoperator with On-Board Power Generator

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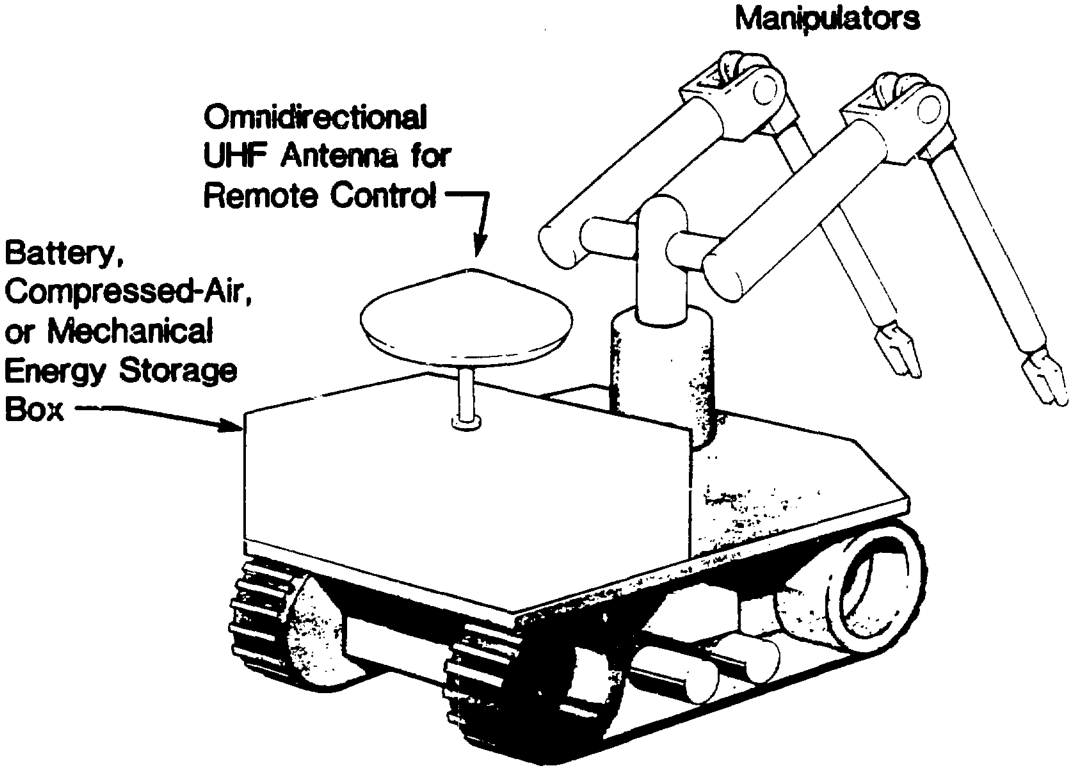

Figure 3. Mobile Vehicle with Energy-Storage Power Source

WIRELESS POWER TRANSMISSION

In the following systems, energy is transmitted though free space to power the vehicle. (Figure 4)

Microwave Power Beam

Microwave energy via line-of-sight beams could be directly transmitted to directive antenna on the vehicle that would collect and rectify the beam energy to the power teleoperator and its mechanisms. Small battery capabilities may be retained to continue operations when direct beam energy became eclipsed. A large battery pack could permit charge, work, and recharge cycles in difficult locations. However, the biological hazard must be considered.

Intense Light Beam (Laser)

A high-powered laser beam can be directed to a photovoltaic array on the vehicle for conversion to electrical power. Light beams can be made exceedingly directive, so that transmitter-to-receiver efficiencies can be quite high. Again, the availability of some on-board battery capabilities would be advantageous for times of beam interruption. A biological hazard to personnel is present.

Inductive Power Loop

A loop could be installed around the inside perimeter of the facility and turned on only when power is needed or when an emergency situation exists. Although power coupling to the mobile unit is inefficient, the power sources would be present throughout the entire facility. A higher-frequency driving loop would increase its coupling efficiency, and the presence of auxiliary battery capacity would assist operations through any heavy loading periods. The vehicle might need "resting" periods while the inductive loop recharges the vehicles internal storage batteries.

SIGNAL/CONTROL TRANSMISSION FOR MOBILE TELEOPERATORS

The following kinds of signal information may be required for remote control applications:

Signal Information

1. Mobile-vehicle drive commands.

2. Manipulator control signals.

3. Position/control feedback data for manipulators.

4. On-board TV video transmissions.

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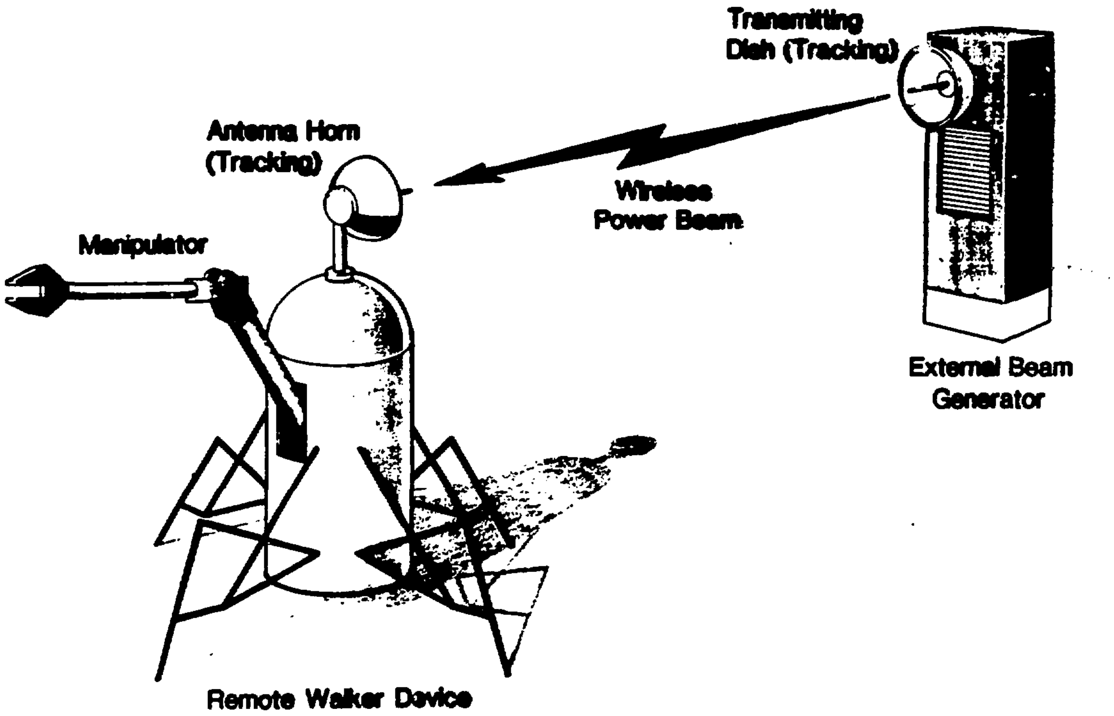

Figure 4. Walker-Teleoperator with Wireless Power Source

5. Temperature measurements.

6. Radiation metering (alpha, beta, gamma, and neutron levels).

7. On-board power and fuel status.

8. Vehicle location navigational coordinates.

Umbilical (Cable or Conductor) Control Signal Transmissions

Multiple, Hardwired Electrical Conductors. Such a cable bundle is trained behind or is fed out to the mobile unit would be subject to the same flexing-breakage and contamination problems as are power umbilicals.

Coaxial Cables. These cables would carry signals either mixed or multiplexed at radio or microwave frequencies. They can be designed to be bidirectional through combiners and circulators, which would result in a cable that is much smaller in diameter than standard cable bundles for a given number of signals transmitted.

Flexible Waveguide. Signals are either mixed or multiplexed and are transmitted at microwave carrier frequencies through a specially designed pipe which is either hollow or filled with a low-loss insulating foam for additional mechanical support. Wire breakage is minimized with a waveguide system, and the cables can be very small for the number of signals transmitted. This method also can be designed for bidirectional operations.

Fiber-Optic Cables. These cables are capable of enormous signal-carrying capacities using a very small-diameter conductor. Technology is currently expanding into many such critical areas of usefulness. Fiber-optic cables are insensitive to electromagnetic interference sources over the entire length of cable run. Bidirectional signal communications are feasible using the appropriate optical systems to correct transmitter and receiver.

Wireless Signal Transmissions (wall penetrations minimized)

The control data for these systems are transmitted through space to the vehicle.

Free-Space Radio Frequency Systems.

a. VHF-UHF radio systems may be operated using directional antennas on the transmitter and omnidirectional antennas on the receiver. The technology for this is well established. The use of reflectors can help overcome blind spots within the facility.

b. Microwave signals can be used over long distances since narrow beams can be formed using dish or horn antennas. These devices have a very large signal-handling capacity, and signals can be mixed or multiplexed and may be made bidirectional. Reflectors could be used to overcome dead areas that were out of the direct beam. Many microwave semiconductor components are intrinsically radiation hardened.

Optical Communications Systems.

a. Visible light may be used for communicating control information; its advantages are that it can be seen and can use ordinary glass optical components. Blind-spot problems within a facility can be avoided by beaming signals toward the ceiling or by using optical reflectors in strategic locations.

b. Infrared (IR) light communications are possible using appropriate IR optical systems. Infrared systems have already demonstrated capabilities for excellent long-distance signal-keeping qualities through haze, fire, and smoke-filled environments. Some newer devices are intrinsically radiation hardened.

Acoustic Transmissions. Acoustic transmissions are sound transmissions of commands through the air from the control site to the vehicle.

a. Low-frequency audio tones can convey control information through the air to audio sensors on the vehicle. Low-frequency transmission has serious drawbacks in the limited number of channels that can be broadcast simultaneously and in the bandwidth of information transmitted. This system would be most useful in controlling sequential tasks that do not require high speeds or complex manipulator actions. Loudspeakers can be used to assert control over long ranges.

b. Ultrasonic carrier tones can be used to increase the number of control frequencies used and can facilitate making the transmitted or received signals more directional. Problems of dead spots in the audio pattern might be solved using multiple ultrasonic transducers prelocated within the facility.

c. Voice recognition equipment can be located on the mobile vehicle that would respond to the controller's voice, either unaided or projected from a loudspeaker. Although only one command can be articulated at a time, the number of stored and recognizable commands at the remote vehicle can be quite large. Although voice recognition technology is in an early stage, recent improvements are remarkable.

On-Board Control

Each vehicle has its own on-board command systems. (Figure 5)

Internally Fixed Preprogrammed Task Schedule. A prescribed group of instructions and operations would be preset. These programs may have sets of commands that help orient the teleoperator to its working site and accomplish routine required tasks; however, it would not have the capabilities for dealing with unusual situations or with conditions that do not conform with internalized plans, routes, or facility designs.

Artificial Intelligence (AI) Capabilities. Artificial Intelligence has the ability to meet the present operational needs and can also adjust and adapt to changes in the presumed plans or expected environment to obtain successful results. The degrees of this ability to adapt can be adjusted to according the difficulty of the projected damage and alterations expected from a facility emergency. AI technologies that can be utilized in this kind of vehicle control are evolving rapidly, and some systems having applicable capabilities are already commercially available.

HYBRID POWER TRANSMISSION AND COMMUNICATION SYSTEMS

Microwave-Power-Information Beams

The intense microwave beam used to power the vehicle also can be modulated with the information needed to control the actions of the mobile unit. Frequency modulation of the carrier is the preferred method to accomplish this. The information signals are separated from the power carrier at the receiving site. The average power to the vehicle does not vary, and some internal continuing programs and storage devices would be necessary to keep the vehicle operating and powered during beam eclipses. Biologic hazards are present with high-power microwave-based system. (Figure 6)

Laser-Power-Information Beams

A highly directional beam of laser energy would be continually aimed at the remote vehicle receiver. The beam would carry frequency-modulated or amplitude-modulated control information methods. Information would be isolated from the carrier beam by photoelectric devices which have very high-frequency response; these would be separate from the on-board photovoltaic generators used for producing vehicle power. Laser beams would also need some form of continuing power and control capabilities to maintain teleoperator operations during beam interruptions. Precautions would be needed for biologic hazards.

SUMMARY CONSIDERATIONS

Special Power Considerations in Remote Teleoperator Designs

1. Power source: Wired, self-contained, or wireless

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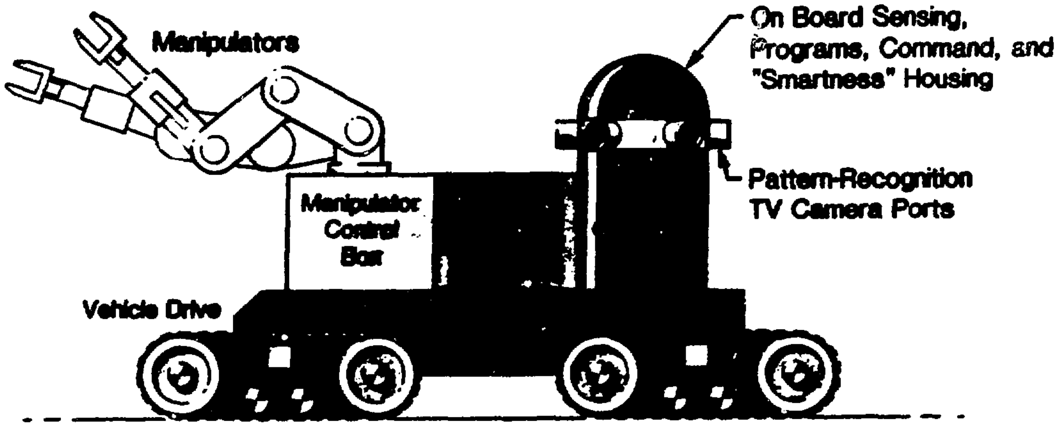

Figure 5. Teleoperator with Self-Contained Programs or Artificial Intelligence

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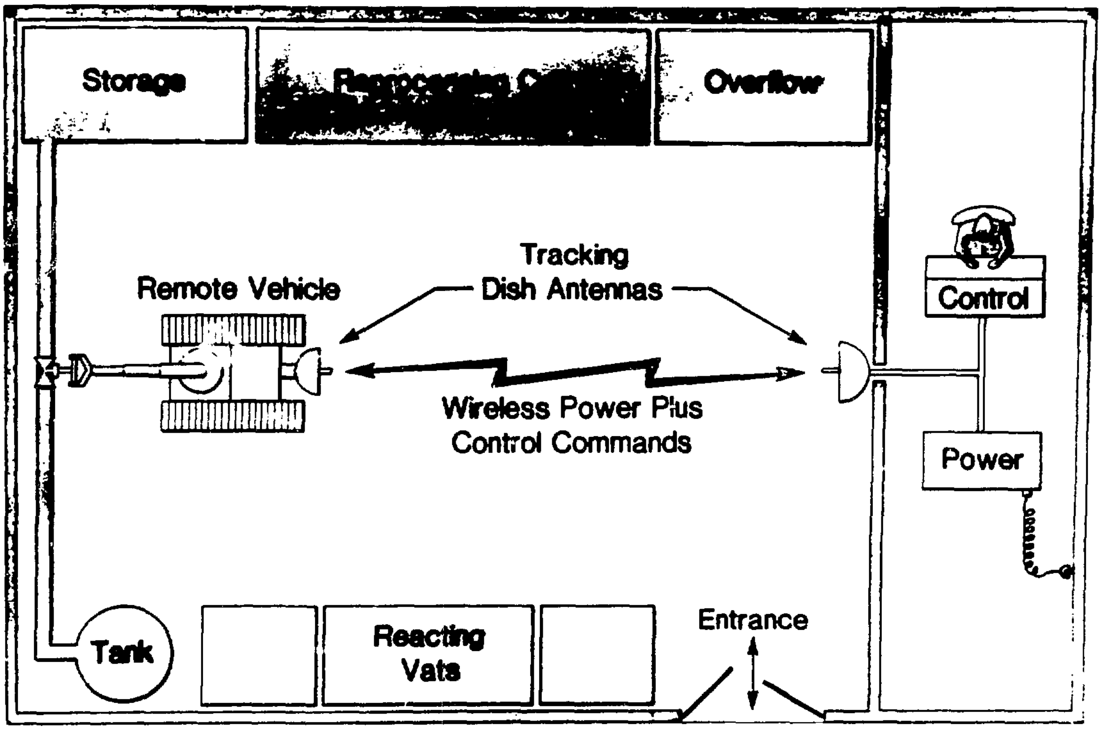

FACILITY PLAN VIEW

Figure 6. Hybrid Mobile Teleoperator with Wireless Power and Control Link

2. Power feed method (power needs to be generated or supplied by facility?)
3. On-board supplementary power storage (back-up battery?)
4. Adequacy of power supply (100 W to 2 kW typical)
5. Effects of contamination and radiation
6. Methods for decontamination (hermetic seals?)
7. Effects of altered atmosphere in facility
8. Size and weight of power source (mechanical supports?)
9. Biological hazards from power source (eye, skin damage?)

Special Control Concerns in Remote Teleoperator Operations (See Table 1.)

1. Command circuits: Umbilical, wireless, or self-contained
2. Radiation hardness of electronics (anticipated doses?)
3. Bidirectional link needs
4. Bandwidth needs (1.0-200 MHz typical)
5. Control speeds required
6. Redundancy in event of circuit failure
7. Interference problems (EMI resistance?)
8. Mechanical size and weight limitations (battery weight and size?)
9. "Smartness" of on-board control circuits

Summary

It is important to match facility design requirements with available options for power and signal transmission early on, carefully considering all possible facility emergency demands and unexpected conditions. The vehicle needs to be designed with a maximum amount of flexibility, adaptability, and redundancy to cope with untoward events and crisis situations.

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Table 1. Signal transmission survey

Properties systems	Slotted line (FM)	Lossy coax (FM)	VHF-UHF radio (FM)	Micro-wave (FM)	Visible light (AM)	Infra-red (AM)	Induct. loop (AM)
RAD-Hard	3[a]	3	2	4	1	1	4
Mechanical size	2	2	2	3	4	4	2
Bidirectional	3	3	3	4	4	4	2
Band-width	3	3	3	5	4	4	1
Bandwidth expand	3	3	2	5	4	4	1
Power level	3	3	2	4	4	4	1
Available technology	3	3	4	4	2	2	2
Maintenance easy	1	2	3	4	4	4	2
Multi-path	5	5	2	3	4	4	4
Bio-hazard	5	5	4	4	3	2	5
Ease of redundacy	2	2	3	4	4	4	2
Avoids interference	4	4	2	5	2	2	2
Low maintenance	3	3	3	3	2	2	4
Score	40	41	35	52	42	41	32

[a] 1 = poor, 5 = very good.

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FOR
REMOTE TELEOPERATED SYSTEMS

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June 25, 1985

I. POWER SOURCES FOR MOBILE TELEOPERATORS

A. Umbilical Systems

B. On-Board Generation

C. On-Board Power Storage

D. Wireless Power Transmission

POSSIBLE UMBILICAL SYSTEMS

- Trailing Cables
- Coiled Cords
- Folded Cable Suspension
- Overhead Swivel Arm

ON-BOARD GENERATION

- **Organic Fuel in Tank**
  - **Produces motor-generator power**
- **Compressed/Liquified Gas Fuels**
  - **Fuel-cell generates electrical power**

ON-BOARD POWER STORAGE

- Lead-Acid Batteries
- NiCad Batteries
- Direct-Drive Compressed/Liquid Gas
- Mechanical Spring-Stored Energy

WIRELESS POWER TRANSMISSION

- Microwave Power Link
- Intense Light Beam (Laser)
- Inductive Loop Inside Facility

COMMUNICATIONS FOR MOBILE TELEOPERATORS

1. Vehicle Drive Commands
2. Manipulator Control Signals
3. Position/Control Feedback Data
4. On-Board TV Camera Video
5. Temperature Measurements
6. Radiation Monitoring (Alpha, Beta, Gamma, Neutron, etc.)
7. On-Board Power and Fuel Status
8. Vehicle Navigational Coordinates

II. COMMUNICATION METHODS FOR REMOTE TELEOPERATORS

A. Hard-Wired Umbilical Communications

B. Wireless Signal Transmissions

C. Preprogrammed Control

HARD-WIRED UMBILICAL COMMUNICATIONS

- **Multiple Electrical Conductors**
- **Coaxial Cables**
- **Flexible Waveguides**
- **Fiber-Optic Cables**

WIRELESS SIGNAL TRANSMISSIONS

- Free-Space Radio Frequency
  - VHF-UHF with directional antennas
  - Microwave beams with horn/dish antennas
- Optical Communication Links
  - Visible light with glass optics
  - Infrared light with IR optics
- Acoustic Transmissions
  - Low-frequency tones
  - Ultrasonic carrier with command tones
  - Voice recognition

PREPROGRAMMED CONTROL

- Fixed Preprogrammed Tasks
- Artificial Intelligence (AI)
  - Has ability to change program steps depending on conditions encountered

III. POSSIBLE HYBRID SYSTEMS

A. Microwave Power-Information Beam: Control Signals Modulated onto Carrier Microwave Beam

- Separated at Vehicle

B. Laser Power-Information Beam: Commands Applied to Light Channel

- Separated by Photocells

IV. EXAMPLE SYSTEM: AIMS SIGNAL INVENTORY

A. Control Station to In-Cell Transporter
   - 3 Megabaud Digital Links (Commands)

B. In-Cell Transporter to Control Station
   - 5 Video Camera Links
   - 3 Megabaud Digital Links (Feedback)
   - 1 Stereo Sound Channel

V. SUMMARY OF POWER CONSIDERATIONS

A. Power Feed Method
B. On-Board Storage (Auxiliary?)
C. Effects of Radiation and Contamination
D. Size and Weight of Power Source
E. Atmospheric (Heat, Smoke, Acid) Effects
F. Biological Hazards

VI. SUMMARY OF SIGNAL CONSIDERATIONS

A. Signal Transmission Methods
B. Radiation Hardness of Electronics
C. Bidirectional Link Needs
D. Redundancy of Signal Link
E. Interference Problems
F. "Smartness" of On-Board Controls
G. Biological Hazards

SUMMARY STATEMENT

A successful remote teleoperated system depends on important early-on matching of facility design requirements with available options for power and signal transmissions and carefully considering all possible emergency facility demands and unusual conditions.

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