

Back to Contents 

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E-mail the Journal 

Journal Staff 

Editorial Board 

Other Issues 



Humanitarian Demining: The Challenge for Robotic Research

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Introduction

Current methods for detecting and removing mines are dangerous, too costly, and, considering the number of abandoned mines, very slow. Mechanical systems are most frequently used to clear large areas polluted by mines. Mechanical systems usually consist of a tank that uses rollers to apply pressure to the ground, rotary flails that beat the ground, or a rake that unearths and presses the mines. The main drawback of purely mechanical demining is that no system can satisfy the desired 100% reliability of humanitarian demining. Consequently, all cleaned areas require manual verification. Thus, an urgent need exists to develop safe and efficient demining methods. This requirement represents a big challenge for robotic research. Research for detecting and localizing mines is still ongoing. In addition to known methods, new sophisticated sensing principles are under development [1,3]. These sensing principles make it possible to detect and recognize mines as hidden objects. Several vehicles equipped with demining technology also are being produced [2].

Robotic Demining Systems

In general, mine-clearing procedures consist of two tasks:

- detecting and localizing landmines, and
- neutralizing landmines (removing or destroying mines in place).

A robotic mine clearance system consists of the following subsystems (See Figure 1):

- **Mobility system.** The mobility system is based on a remotely controlled semiautonomous mobile (robotic) vehicle that functions as the unified porter of other equipment for detecting and neutralizing mines. Conditions and requirements for solving such a mobile robot are briefly discussed below. Two examples are also given.

- **Multi-sensorial system for detecting and recognizing mines.** In principle, the sensory system can be situated either on a special platform for scanning dangerous terrain in front of the vehicle or behind the vehicle for verifying the demining procedure.
- **The system for destroying and neutralizing mines.** In addition to mechanical systems such as rollers, ploughs, flails, and rakes, other principles can be used to activate mine explosions. Such principles include explosive hoses, fuel air mixture, directed energy systems, laser technologies, microwave technologies, and sniper rifle. The positions and coordinates of objects that are recognized as mines are used as input data.
- **Control and communication systems.** The principle requirement is that such a demining vehicle should operate in a remote control mode or, at least, semi-autonomously. A general control system includes mobility navigation and control, positioning of the sensing or marking apparatus, and target positioning for the destruction system. The communication system transfers large amounts of control and sensory data to the operator.

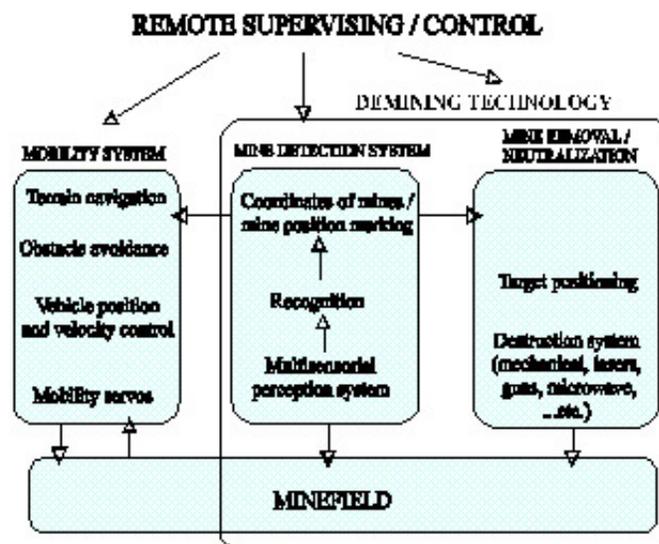


Figure 1: Global scheme of a robotic semiautonomous demining system

Detecting and Localizing Mines

Sensory equipment for detecting and localizing mines plays a crucial role in any demining system. The table below (Table 1) presents several potential sensing technologies that are capable of detecting and recognizing mines [6]. When comparing these technologies, one can see that each of them exhibits some specific efficiency features; however, one must also take into consideration the cost and complexity. It is clear that no single sensor can detect all kinds of mines. Instead, a fusion of information from several sensory systems is required.

Sensor technology	Maturity	Cost and efficiency	Non-metal mine detection
Metal detection	Available	Low	+
Infrared	Near	Medium	+++
Electro-optical	Near	Medium	+++
Multi/hyper spectral	Far	High	++
Passive mm-wave	Far	High	++
Mm- wave radar	Near	High	++
Ground Penetrating Radar	Near	Medium	++
Ultra-wide-band radar	Far	High	++
Active acoustic	Mid	Medium	++
Active seismic	Mid	Medium	+++
Magnetic field sensing	Near	Medium	+
Neutron activation analysis	Near	High	+++
Charged particle detection	Far	High	++
Nuclear quadrupole	Far	High	+
Resonance	Mid	High	+
Chemical	Far	High	+++
Bio-sensors	Available	Medium	+++
Dogs / rates	Available	Low	+++
Prodding			

+++ (good) + (poor)

Table 1

Robotic Technology Requirements

When building robotic technology, one first needs to build a universal all-terrain robotic system that is highly mobile and lightweight. Furthermore, this system should be able to be used in demining work anywhere around the globe. Although such a system could be realizable when one takes the current state of technology into consideration, there is no reason to spend so much money and enormous human effort to develop such a complicated high-tech system. Instead, a robotic system should satisfy specific conditions directly related to its local application. We outline some of these below.

General. Mines are deployed mainly in poor, third-world countries where salaries for this dangerous work are relatively low. Under such conditions, using standard hand-searching technologies is more advantageous. The local population's technical knowledge is very limited

and access to high-technology components is almost nonexistent. Local materials, local manufacturing, and local manpower should be used to perform demining operations and to maintain all technology.

Mechanics. Low-tech and lightweight mechanics are highly desirable. An example is a bicycle-like solution with practically all components locally available and easily repairable anywhere in the world.

Electronics. Hardware and software parts do not have to be built based on the most sophisticated technology. More importantly, all systems should be resistant to occasional explosions or any possible actions due to errors, such as operator errors or shocks during transport.

Sensors. Development and availability of cheap, lightweight, reliable sensors can certainly solve the majority of demining problems.

Control. Remote or semi-autonomous control that reduces the risk to human operators is desirable. The complexity and level of training for local operators should correspond to their local talent and technical education. An understandable and robust system with minimum training effort is preferred.

Operational requirements

A robotic system should meet some essential requirements, which are proposed below. Essential requirements are not discretionary; desirable requirements appear in parentheses and are for guidance.

Reliability: 100% clearance

Depth of demining: 20 (50) cm

Width of Clearance: 3.0 (4.0) meters

Speed of Clearing: 3.0 (5.0) km/hr

Slopes during demining:

Longitudinal: 20% (25%)

Lateral: 10%, (15%)

System deployment: To be self-deployed to operation location.

- Self recovery:** Vehicles can operate in pairs. Each system should have a winch so that a second vehicle can recover the first.
- Obstacles:** The system should be able to operate and overcome obstacles characteristic of and specific to a particular post-war country. Such obstacles include ditches and old trench systems, water or mud terrain, stones, sand, holes, trees, bamboo, and coppice.
- Climatic conditions:** Conditions to be considered include working temperatures, humidity, rains.
- Types of mines:** Any density or types of mines are possible.

Examples of two robotic systems are given below.

A Cable-Suspended Robotic Platform for Searching Dangerous Terrain

The cable-suspended robotic platform [4] in Figure 2 consists of three columns with winch mechanisms, such as cable drivers and measuring systems built on remotely controlled vehicles. The ends of the cables are fixed to the moving platform. This parallel kinematic structure exhibits 3 d.o.f. positional capability above the terrain. This configuration exhibits the following advantageous features:

- large workspace of operation that is reconfigurable according to actual terrain conditions,
- lightweight and easily transportable,
- fast and simple on-site installation, as well as
- operation and control with Cartesian coordinates that are defined directly on site.

The platform is equipped with several ultrasound sensors that enable operators to control its motion within a given distance over dangerous terrain as well as to avoid any obstacles when performing searching motions.

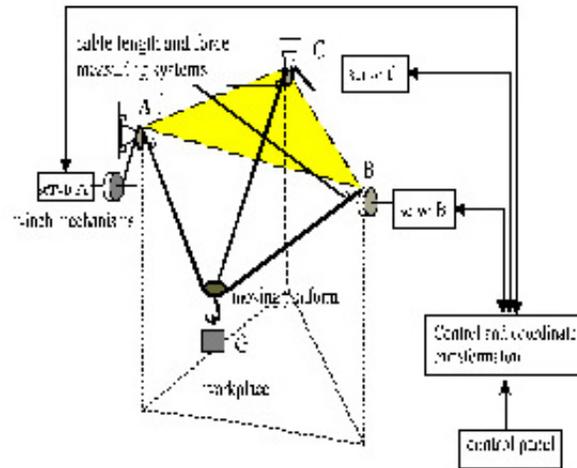


Figure 2: Principal mechanical configuration

The platform carries equipment for detecting and neutralizing mines. When performing scanning motions, it is possible to create a map of all objects that have been detected and recognized as mines (see Figure 3).

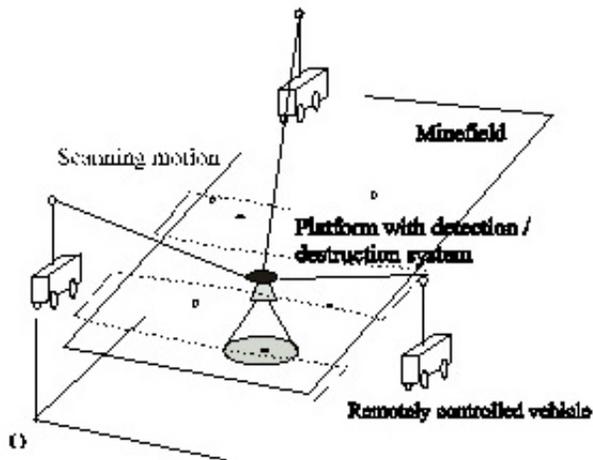


Figure 3: Concept of the demining operation

Four main problems have been solved for this system. These are

- kinematic and force analysis,
- coordinated motion control in global coordinates,
- dynamic analysis and control, as well as
- calibration.

The Bozena Demining Flail

System Concept

Several vehicles equipped with such devices have been built mainly based on military vehicles. The system discussed below represents a further modification of the small loader—that is, a vehicle that manipulates loose materials and terrain works.

The importance and real need for a demining system motivated our researchers and design engineers to develop a multipurpose system that could be applied to and should satisfy military requirements for demining operations as well as general civil purposes. The new development of this machine was oriented towards the following applications:

- demining operations;
- engineering works in civil protection;
- works in hazardous situations, ecological disasters, etc.

Based on the mechanical solution of the universal loader, new additional demining equipment has been developed. The BOZENA demining system consists of the following functional parts (see Figure 4):

- universal vehicle for terrain manipulation, a soil loader, and a maneuvering vehicle;
- a radio communication system for teleoperation and remote control;
- two flailing mechanisms with rotating chains and hammers (these mechanisms can be manipulated in 2 d. o. f. according to working conditions);
- covers for mechanical protection against explosions of mines; as well as
- tracks and palettes for transport.

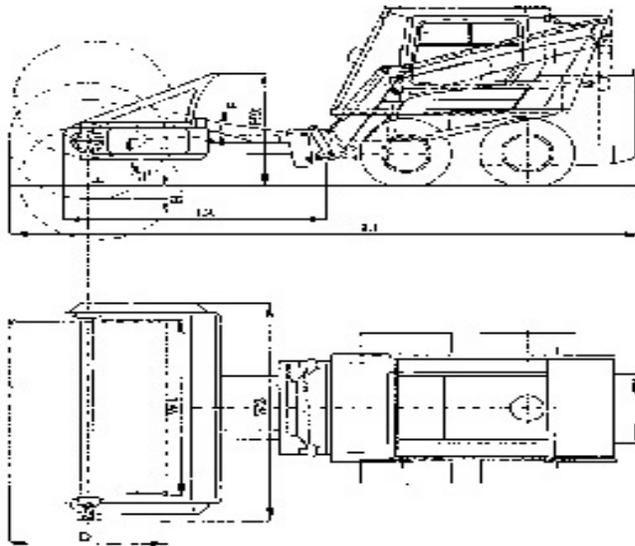


Figure 4: Side and top view on the demining vehicle

$L1 = 5282 \text{ mm}$, $L2 = 2180 \text{ mm}$, $W1 = 1985 \text{ mm}$, $W2 = 2457 \text{ mm}$, $D = 1300 \text{ mm}$, $H1 = 150 \text{ mm}$.

Description and Technical Specifications

Some parameters and operating characteristics for the BOZENA system are listed below.

Slope angle of the terrain where the unit is able to work:

in lateral direction	10 degrees
in transversal direction	20 degrees

Speed of demining	0.7 up to 3 km/h
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Width of demining area	2 m
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Depth of flailing hammers	0.15 m
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Maximum distance for remote control	5 km
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Time for preparing the vehicle for operation	30 min.
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Experience from Real Demining Operations

The BOZENA demining system (see Figure 5), which was verified under real conditions, is used by Slovak and Czech military peacekeeping forces in the former Yugoslavia for clearing post-battle minefields. This demining system exhibits some important advantages over other existing demining techniques. These include

- speed of demining operations,
- low cost and high efficiency expressed as total cost per unit of

cleared,

- lower psychological pressure for service persons because vehicle is controlled remotely,
- multipurpose use of system (loader and maneuvering unit can be combined with 18 additional accessories), as well as
- fast and low cost transport over long distances.



Figure 4: "BOZENA" prepared for demining operations"

Conclusion

Detecting and neutralizing landmines are big challenges facing researchers working in several disciplines. Targeted research is especially desired in the following domains:

- **Robotics.** Such a robot should be an autonomous or semi-autonomous vehicle that is easily transportable and cheap. It should be able to move along various terrain features (such as holes, slopes, and stones), negotiate possible obstacles (such as trees, weed coppice, wickets, and water), as well as resist mine explosions. To neutralize mines, it is equipped with one or several appropriate mine-explosion activating systems.
- **Sensing technology for mine detection.** Detecting and localizing landmines has a crucial importance in demining operations. Considering the great number of types of mines produced (different forms, materials, and colors), the variety of terrain features, and the endless possibilities of hiding mines, reliable equipment should use more sensing techniques and fusing sensory information to detect mines. Naturally, this requires the elaboration of reliable recognition algorithms.

- **Sensing, information processing, and communication for mobile systems.** The recognition and information systems include several smart sensors needed for remote mobility control, obstacle avoidance, and navigation.
- **Control.** The remote operation of the mobility, sensorial, and mine-destruction systems suggest a decentralized modular architecture of the control. Such a control system should be built taking outdoor working conditions, as well as the total cost of the demining system, into consideration.

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