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Naota Furihata
Tokyo Institute of Technology

Shigeo Hirose
Tokyo Institute of Technology

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Development of mine hand

An Extended Prodder for Protected Demining Operations

by Naota Furihata and Shigeo Hirose [Tokyo Institute of Technology]

Manual operations remain indispensable in the demining process despite the use of heavy machines in the field.¹ Although considerable research has focused on demining sensors,^{2,3} automated machines^{4,5} and heavy machines,^{6,7} research has paid little attention to devices used in manual operations. The objective of this paper is to detail the development of a new device for manual operations. This machine increases the safety of manual operations and aids in the most dangerous process of APM removal.

Concept of Mine Hand

Considering the necessity of tools for manual clearance operations, a mechanical, remote-controlled hand was created that can be operated from a remote location about 1 to 2 meters (about 1.1 to 2.2 yards) away from a mine without using electricity. This configuration provides the following advantages:

1. The mechanical master-slave hand is effective in locations where electricity may be scarce and maintenance impractical. Although instruments using electrical transmission, such as the electric master-slave hand,⁵ enable operators to approach landmines from very long (and by extension, safe) distances, they are not suitable for field operations because they are too complex, too fragile and require electricity.
2. The blast of a landmine goes up and spreads at an angle of about 30 degrees (see FIGURE 1). Therefore, the conventional removal process that uses simple prodders and scoops^{8,9} is very dangerous. The safety of this process can be improved if operators approach the mine through shields and operations outside the blast zone (see FIGURE 1).
3. Because the hand is mechanical, the tactile information of digging soil is easily transmitted to the operator as with hands used in an atomic power plant,¹⁰ which is important in delicate operations like demining.

Design of Mine Hand

The symmetric motion transmission is a central aspect of the Mine Hand-1 design. It is composed chiefly of two parts: the arm and the base (which supports the arm). Details of these mechanisms are given below.

The arm of Mine Hand-1. The arm mechanism is illustrated in FIGURE 2. The master and

slave hands, which have the same form at both ends, are mated to the outer pipe. These hands have three degrees of freedom (DOFs): two for the pitch (θ_p) and yaw (θ_y) hand posture motions and one for its grabbing motion (θ_g). Three thin rods, each with one DOF, are passed through the thick pipe. The motions of these three rods transmit the three DOFs from the master to the slave hand.

An enlarged view of the master side is shown in FIGURE 3. This kinematical system has 19 links and 21 passive joints with one DOF, thus resulting in three DOFs total. These three DOFs of fingers are changed into motions of three inner rods and are transmitted to the other side. A ball bearing was used for all of the passive joints for proper haptic transmission.

es the machine's weight, thus hindering portability. For this reason, we did not adopt it. Instead, we decided to use springs to compensate the weight. The specifications of the Mine Hand-1 are shown in TABLE 1.

Basic experiment. We conducted basic operating experiments with Mine Hand-1, which demonstrated its ability to dig out soils and accomplish the fine tasks needed for manual operation. Furthermore, we could distinguish between soft and rigid materials.

Mine Hand-2

Test of Mine Hand-1 with the directors of MACA. After Mine Hand-1 was completed, we conducted demonstrations and qualitative tests of it with the directors of the Mine Action

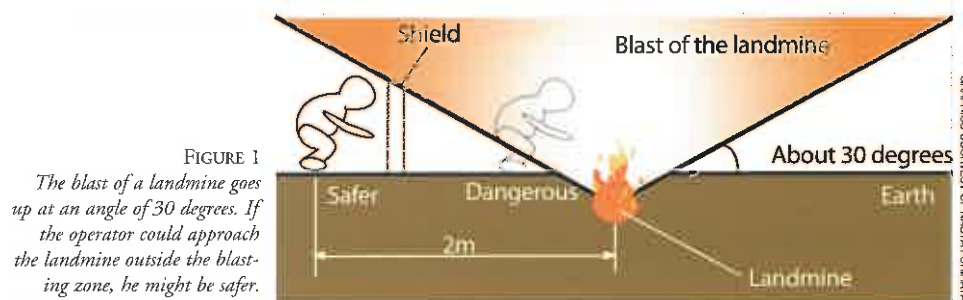


FIGURE 1
The blast of a landmine goes up at an angle of 30 degrees. If the operator could approach the landmine outside the blasting zone, he might be safer.

TABLE 1: Specifications of Mine Hand-1.

Length	2300–2800 mm
Width	1200 mm
Height	400–600 mm
Weight	60 kg
Length of the arm	1600 mm
Stroke of the arm	500 mm

Base of Mine Hand-1. The base of the left arm and its movements are illustrated in FIGURE 4. This mechanism has four DOFs. Two DOFs in the vertical plane (y, z) become possible by two rotating joints, one DOF for posture of the arm (θ_p) by one rotating joint and the last DOF for horizontal direction (x) by prismatic joint. The symmetric motion increases the mechanism's ease of use. Both the master and slave sides move in the same direction.

The design of Mine Hand-1 produces a heavy mechanism that is cumbersome, thus causing operator fatigue. Two methods were considered for weight compensation—counterweights and springs. The counterweight method is able to compensate its movement perfectly and results in a simple structure; however, this method increases

TABLE 2: Specifications of Mine Hand-2.

Length	1800–2900 mm
Width	600 mm
Height	600 mm
Weight	9.25 kg
Length of the arm	1500 mm
Stroke of the arm	1100 mm

Centre for Afghanistan (MACA). The results were as follows:

1. The three-DOFs arm is too complicated for use in severe situations. Much simpler and stronger tools are necessary.
2. The base is too heavy. Because landmines are buried in many places, a light and portable tool is better.
3. Tools that can generate enough force to dig out hard soil are necessary.

The Mine Hand-2 is an improved model that incorporates the above design observations.

Design of Mine Hand-2. A brief line drawing of Mine Hand-2 is shown in FIGURE 5 and its specifications are in TABLE 2.

In the center of the shield of Mine Hand-2, a spherical joint is assembled, and the pipe of the

arm is passed through this joint. This spherical-prismatic mechanism allows four DOFs. The advantages of this mechanism are its simple structure, ease of affixing a shield and portability. Furthermore, it can generate a large force for digging the ground by mechanical leverage. Polycarbonate was used for its shield as it has good fracture toughness and transparency. The master and slave sides of Mine Hand-2 move in opposite directions—thereby decreasing ease of use—yet this limitation can be overcome with brief training and practice.

As for the arm, we reduced two DOFs from the previous model, leaving the arm with just one DOF for grasping. Opening and closing motions of the trigger in the master hand are transmitted to the slave hand through the thin inner pipe. A brief drawing of the master and slave sides is shown in FIGURE 6 (next page).

Operators do their fine work with brushes. While brushes can be attached to the slave hand, an exhaust nozzle is installed at the front for blowing sand. An air accumulator is suitable for such a task and can be charged by a mechanical pump or using a solar battery.

So that it can be easily carried, Mine Hand-2 is lightweight. It weighs 10 kg, which is one-sixth the weight of Mine Hand-1. Hooking the arm to the chair provides a handle for carrying ease.

In demining tasks, operators must change their working positions frequently. In order to improve working efficiency, the mechanism can rotate around the chair and expand its workspace as shown in FIGURE 7 on Mine Hand-2 (next page). Because the chair is a supporting point of Mine Hand-2, the operator can let Mine Hand-2 rotate by simply inclining his body slightly backward like a seesaw.

Exploding Experiment

Outline of the exploding experiment.

We conducted blast tests on the Mine Hand-2 by using imitation landmines, exploding two of them. One was an MS-3 (310 g of TNT), which is the most typical APM. The other was an M16A2 (601 g of TNT), one of the strongest landmines available. Two Mine Hand-2 units were tested with the MS-3 and three units were tested against the M16A2. A side view of the experimental setup is shown in FIGURE 8 (next page), and details about experiments are described below.

The exploding experiment of MS-3.

MS-3 refers to landmines that are buried in the ground and blow upward. This time, we set the mine 50 mm underground. We laid a 60-kg sandbag on a chair instead of a human operator. We tested two Mine Hand-2s, which have shields that are 10 mm thick.

The exploding experiment of M16A2.

An M16A2 is a landmine used to effectively kill humans because it scatters into pieces when it explodes. Therefore, we set it 300 mm underground, set a 60-kg sandbag again and tested

FIGURE 2
CAD graphic of the arm.

The outer thick pipe is drawn semi-transparent to show the rod-only transmission. The subscript "m" means master side and "s" means slave side. The master and slave hand with three DOFs is attached at both tips of the outer pipe, and these three DOFs are transmitted through three inner rods.

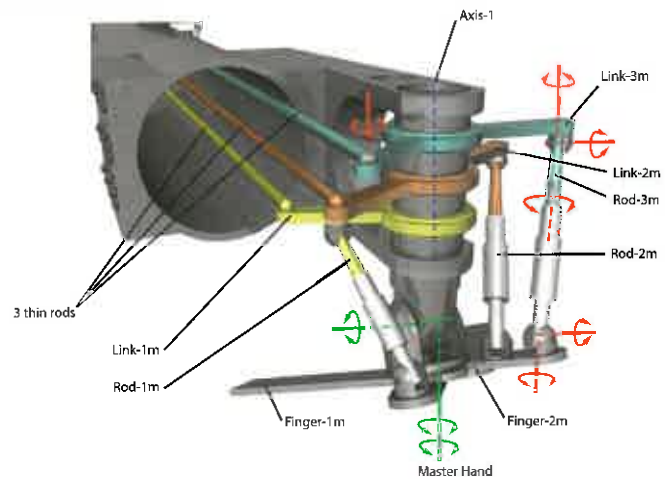
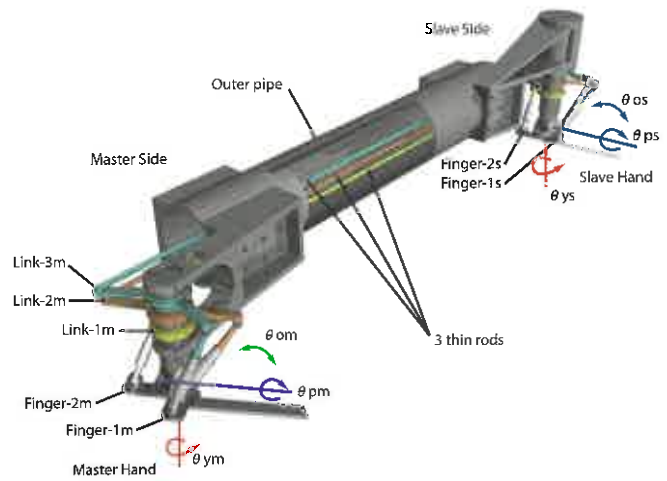


FIGURE 3
CAD graphic of master side. Linear motions of Links 1, 2 and 3 are converted into rotating motions of Finger 1 and 2 by Rods 1, 2 and 3.

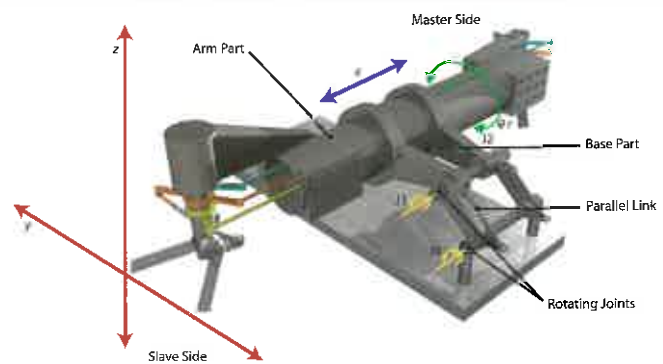


FIGURE 4
The supporting part of the arm. This part has four DOFs.

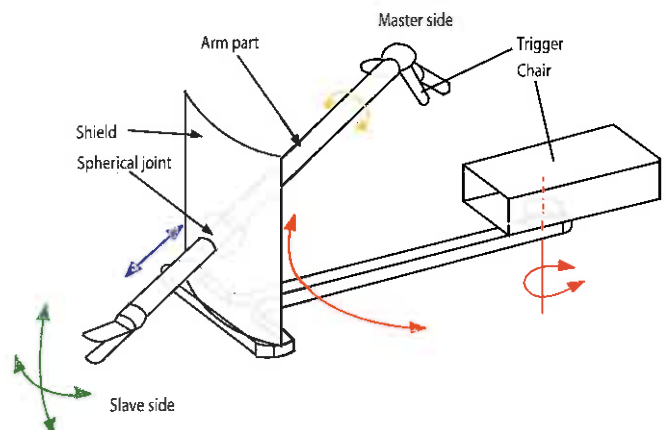


FIGURE 5
Brief line-drawing of Mine Hand-2.

3D IMAGES COURTESY OF NAOKI FUJIMATA / DONOVAN DOUGLAS

three Mine Hand-2s. Two of them had shields 10 mm thick and one was 15 mm thick.

Force sensor. We fixed a force-measuring instrument at the master side of the arm to estimate how much impact force is applied when the arm is struck. A photograph and line drawing of this force sensor are shown in FIGURE 9. A hemispheric lead is attached at the end of the arm and is covered by a bowl that has spikes. When this bowl strikes somewhere, holes are made in the surface of the hemispheric lead. The impact force can be estimated by measuring the depth of these holes.

Result of MS-3. Although the slave hands of both Mine Hand-2s were damaged, the shield

remained largely unscathed. No hole was found in the hemispheric lead of the force sensor. Therefore, it can be assumed that both master sides did not collide.

Result of M16A2. Every Mine Hand-2 was blown 1 to 2 meters (1.1 to 2.2 yards) backward by the blast. Shields with 10-mm and 15-mm thickness were penetrated by shrapnel and were bent by the shockwave. Sandbags standing in place of the human operator fell forward because of the inertial force.

Summary of the test. From these experiments, it can be stated that operators of Mine Hand-2 are safe against MS-3, which is generally used and explodes in the ground. In the case of a

large, scattering landmine, we found that even 15-mm-thick polycarbonate is not sufficient. We measured the depth of the holes that were made in the force sensor. The impact force upon the master side was at a maximum of 2300 N.

Conclusion

This paper suggests a novel, mechanical master-slave hand for manual demining operations. The two mechanical arms—Mine Hand-1 and the simple, robust Mine Hand-2—require no electricity and can be easily operated.

Mine Hand-1 has seven DOFs and can dig out soil and perform fine work; however, in consultation with MACA, the mechanism was deemed too complicated and heavy for use in severe conditions like those in Afghanistan. This hindrance led the designers to develop the simple, practical, lightweight Mine Hand-2 with non-symmetric motion and five DOFs. From the blast experiments conducted on the Mine Hand-2, it can be stated that operators are safe even if common landmines were exploded by accident. For future work, we will improve the ease of use of Mine Hand-2 and prepare it for use by actual deminers. As for Mine Hand-1, we are planning to use this hand to handle sensors. ♦

See "References and Endnotes" on page 109

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Contact Information

Naota Furihata
 Department of Mechanical and Aerospace Engineering
 Tokyo Institute of Technology
 2-12-1 Oo-okayama Meguro-ku
 Tokyo, Japan
 152-8552
 Tel: +81-03-3748-5367
 E-mail: furihata@robotics.mes.titech.ac.jp

Shigeo Hirose
 E-mail: hirose@robotics.mes.titech.ac.jp

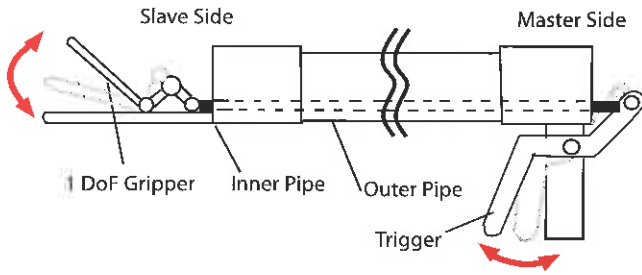


FIGURE 6 Mechanism of one-DOF gripper. Opening and closing motions of the trigger in the master hand are transmitted to the slave hand through the thin inner pipe.

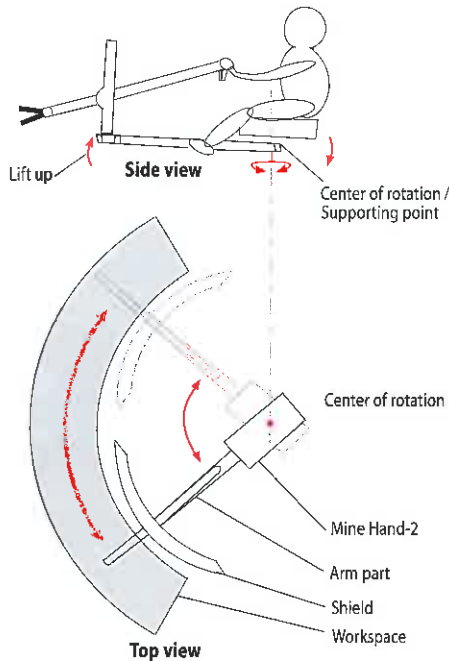


FIGURE 7 Expanded working space. Mine Hand-2 rotates around the chair and expands its workspace.

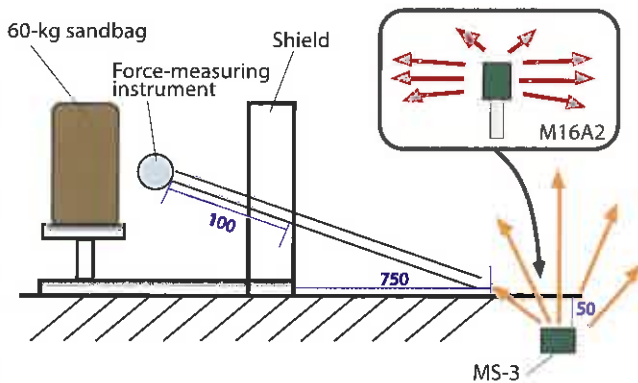
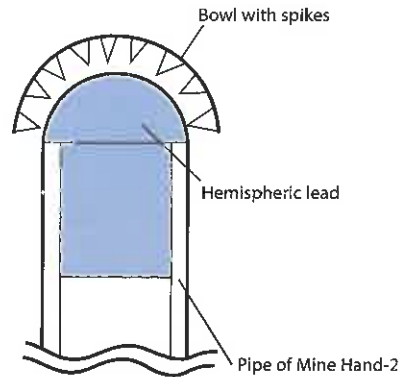


FIGURE 8 Experimental setup of MS-3 blast test.

FIGURE 9 Force-measuring instrument. A hemispheric lead is attached at the end of the arm and is covered by a bowl that has spikes.



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