Development of Mine Hand: An Extended Prodder for Protected Demining Operations
by Natsia Forubad and Shiges Hirose | Tokyo Institute of Technology

11

usual operations remain indis- pectable in the demining process despite the use of heavy machinery. In the field. Although considerable research has focused on demining systems,1 automated machines2 and heavy machines,3 recent has failed to ensure trans- fer 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 mine with- out 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 impracticable. Although instruments using electrical transmission, such as the electric master-slave hand, are stable for operations in 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. Therefore, the conventional removal process that uses simple provers and scoop6 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 readily transmitted to the operator as with hands used in an atomic power plant,7 which is important in delicate operations like demining.

Design of Mine Hand

The symmetric movement transmission is a cen- ter of the Mine Hand design. It is com- posed chiefly of two parts the arm and the base (which supports the arm). Details of these mec- hanisms are given below.

The arm of Mine Hand-1. The arm mechan- isms is illustrated in Figure 2. The master and slave hands, which have the same form as both ends, are mounted to the outer pipe. These hands have three degrees of freedom (DOF) for two hands and yaw (y) head posture motion and one for its grabbing motion (z). Three rods, each with one DOF, are passed through the slave ends trans- mitting the three DOF from the master to the slave hand.

An enlarged view of the master side is shown in Figure 3. This kinematic 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 rock and are transmitted to the other side. A ball bearing was used for all of the passive joints for proper lacking motion.

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The blast of a landmine goes up at an angle of 30 degrees. Therefore, the operator could approach the landmine outside the blast zone, he might be safe.

TABLE 1: Specifications of Mine Hand-1

<table>
<thead>
<tr>
<th>Specification</th>
<th>Length</th>
<th>Width</th>
<th>Height</th>
<th>Weight</th>
<th>Length of the arm</th>
<th>Stroke of the arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine Hand-1</td>
<td>2300–2800 mm</td>
<td>1200 mm</td>
<td>400–600 mm</td>
<td>60 kg</td>
<td>1600 mm</td>
<td>500 mm</td>
</tr>
</tbody>
</table>

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 of the vertical parts (y, z) become possible by two rotating joints, one DOF for posture of the arm (y, z) by one rotating joint and the last DOF for directional action (y) 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 machine that is cumbersome, thus causing operating fatigue. Two methods were considered for weight compensation—counterweight and the center of gravity. The center gravity method is able to compensate its movement perfectly and results in a simple structure; however, this method increases 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.

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

Mine Hand-2

Test of Mine Hand-1 with the director of MACA. After Mine Hand-1 was completed, we conducted demonstrations and qualitative tests of it with the director of Mine Action Centre for Afghanistan (MACA).

Explosive Experiment

Collar of the mine-hand is fixed to the center of the explosive. We conducted trials on the Mine Hand-2 by using initiation landmines, expediting two of them. Other than (350 mm of TNT), which is the most typical AP5. The other was a M162 (301 g of TNT), one of the strongest landmines. Two Mine Hand-2 units were used with the two landmines and three units were tested against the M162. A side view of the experimental setup is shown in Figure 8 (next page), and details about experiments are described below.

The exploision experiment of M162. M5-5 refers to landmine that is buried in the ground and blown up. This time, we set the mine 50 mm underground. We laid a 60 kg sand- bag on a chair instead of a human operator. We tested two Mine Hand-2 units which have shields that are 50 mm thick.

The exploision experiment of 20162. M162 is a landmine used to effectively kill humans because it scatters into the area it explodes. Therefore, we set it 300 mm underground, set a 60 kg sand-bag again and used...
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Visual operations remain indispensable in the demining process despite the use of heavy machinery. Although considerable research has focused on demining systems and autonomous machines, recent developments have targeted the use of devices with limited human intervention 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 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 impossible. Although traditional instruments using electrical transmission, such as the electric master-slave hand, enable operators to approach landmines from a long distance (and by extension, safer) they are not suitable for field operations because they are too complex, too fragile, and require electricity.
2. The hand is functional and can be used in an off-the-shelf configuration without additional training.
3. Because the hand uses mechanical and tactile information, digging and lifting is done with manual exertion of force.

Design of Mine Hand

The symmetrical movement transmission is a central aspect of the Mine Hand design. It is composed of two parts: a slave arm (the mine that supports the arm) and the base (which supports the arm). Details of the mechanism are given below.

The arm of Mine Hand-1

The arm mechanism is illustrated in FIGURE 1. The master and slave arms, which have the same form at both ends, are mounted on the outer pipe. These hands have three degrees of freedom (DOFs): two for the pitch (65) and yaw (61) hand pivot motions and one for its grabbing motion (62). Three tools, each with one DOF, are passed through the pipe; the motions of these three tools transport the three DOFs from the master to the slave hand.

An enlarged view of the master side is shown in FIGURE 2. This kinematic 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 rock and are transmitted to the outer side. A ball bearing was used for all of the pivot joints for proper latching function of the machine.

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<th>Mine Hand-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>1200 mm</td>
</tr>
<tr>
<td>Width</td>
<td>600 mm</td>
</tr>
<tr>
<td>Height</td>
<td>600 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>9.25 kg</td>
</tr>
<tr>
<td>Length of arm</td>
<td>1500 mm</td>
</tr>
<tr>
<td>Stroke of arm</td>
<td>1100 mm</td>
</tr>
</tbody>
</table>

Compared to Mine Hand-1, the base of the arm and its movements are illustrated in FIGURE 3. This mechanism has four DOFs. Two DOFs for the vertical planes (9, 10) become possible by two rotating joints, one DOF for posture of the arm (11) by one rotating joint and the last DOF for horizontal direction (12) by prismatic joint. The symmetric motion increases the mechanism's rate of use. Both the miner and slave sides move in the same direction.

The design of Mine Hand-2 produces a heavy duty machine that is capable of handling larger objects.

Expanding Experiments

Compared to Mine Hand-2, the arm mechanism incorporates the above design observations.

Design of Mine Hand-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-geometric mechanism allows four DOFs. The advantage of this mechanism is its simple structure, ease of affixing a shield and porosity. Furthermore, it can generate a large force for digging the ground by mechanical leverage. Polycarbonate was used for its shield as it has good fatigue toughness and transparency. The master and slave sides of Mine Hand-2 move in opposite directions—slightly decreasing one use—but this limitation can be overcome with a small hand and training.

For the arm, we reduced two DOFs from the previous model, leaving the pinch (65) and yaw (61) hand pivot motions and one DOF for grasping. Opening and closing motions of the inner rock in the master hand are transmitted to the slave hand using a lead screw. A brief drawing of the master and slave sides is shown in FIGURE 7 (next page).

Operate the arm with a button. While the button is pushed, the arm will move at the front for blowing sand. An air actuator is used for this task and can be charged by a mechanical pump or using a solar battery.

In demining tasks, operators must change their working positions frequently. In order to improve working efficiency, the machine 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 suspension-type one, Mine Hand-2, the operator can operate Mine Hand-2 by simply inclining his body slightly backward. This is a novel concept.

The expanding experiment of MS-5, MS-3 refers to landmines that are buried in the ground and blown up. This time, we used two Mine Hand-2 units were tested against MS-3 and three units were tested against MS-4. A side view of the experimental setup is shown in FIGURE 8 (next page), and details about experiments are described below.

The expanding experiment of MS-5, MS-3 refers to landmines that are buried in the ground and blown up. This time, we used two Mine Hand-2 units. We laid a 50 kg sandbag on a chair instead of a human operator. We tested two Mine Hand-2 units that have shields that are 15 cm thick.

The expanding experiment of 2016-2. Mine Hand-2 is a landmine used to effectively kill humans, because it is inserted into the ground and explodes. Therefore, we set it 300 mm underground, set a 60 kg sandbag against it, and moved 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-geometric mechanism allows four DOFs. The advantage of this mechanism is its simple structure, ease of affixing a shield and porosity. Furthermore, it can generate a large force for digging the ground by mechanical leverage. Polycarbonate was used for its shield as it has good fatigue toughness and transparency. The master and slave sides of Mine Hand-2 move in opposite directions—slightly decreasing one use—but this limitation can be overcome with a small hand and training.

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thirteen Mine Hand-2. Two of them had shield 10 mm thick and one was 15 mm thick.

**Furano sensor.** We fitted 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 hemispherical lead is attached at the end of the arm and is covered by a hood that has spikes. When this hood strikes somewhere, holes are made in the surface of the hemispherical lead. The impact force can be estimated by measuring the depth of these holes.

**Result of MS-2.** Although the slant horns of both Mine Hand-2s were damaged, the shield remained largely unchanged. No bore was found in the hemispherical lead of the force sensor. Therefore, it can be assumed that both master sides did not collide.

**Result of M14A1.** Every Mine Hand-2 was blown to 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. Sandings standing in place of the operator fell forward because of the inertial force.

**Summary of the test.** From these experiments, it can be stated that operation of Mine Hand-2 is safe against MS-3, which is generally used and exploded in the ground. In the case of a large, scattering handmine, 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-3 has seven DOFs and can dig. We will perform full-scale experiments in the near future. Data on handmines and sandings are expected to make it possible to use this new method of hand handling.

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**Figure 1.** Photograph of the Furano force sensor. A small lead cylinder is attached to the electrode lead. The lead cylinder is protected by a hood.

**Figure 2.** Photograph of the force-measuring instrument. A hemispherical lead is attached at the end of the arm and is covered by a hood that has spikes.

**Figure 3.** Photograph of Mine Hand-2. The MS-3 Mine Hand-2 blasts through the sleeve and inner pipe.

**Figure 4.** Photograph of the force-measuring instrument. A hemispherical lead is attached at the end of the arm and is covered by a hood that has spikes.