

## Tele-Robotic System for Recovery of Buried Munitions in China

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The destruction of chemical weapons is an ongoing activity regulated by the signatories of the chemical weapons prohibition treaty. In accordance with the memorandum and the understanding by the governments of Japan and China (GOJ and GOC) regarding the abandoned chemical munitions in China, the Japanese Cabinet Office is proceeding with the Destruction Project of Abandoned Chemical Weapons (ACW) in China. ACW are located in the northeast provinces in China. Specifically, several hundred thousand munitions are buried in the two burial pits in the Haerbaling area of Dunhua in Jiling Province. The work of ACW Destruction Project is to excavate, classify and pack the buried munitions, and finally to destroy them in a specialized plant after temporary storage. Careful handling is required in all processes to avoid the potential risks of munitions detonation and exposure to chemical agents. So far, a series of proof-of-concept tests have been performed and the performance verified for the excavation system's main components, such as the munitions gripper, the soil retrieval subsystem consisting of air injection and extraction nozzles. Recent technical innovations in the field of the telerobotic systems are now readily available and a reliable telerobotic system can be developed and demonstrated shortly.

This paper outlines only two aspects (excavation machinery and soil removal system) of ACW Destruction Project from the viewpoint of the Project Management consultant that is supporting ACW office.

### 1. Introduction

From 1951 to 1963, several hundred thousand abandoned chemical munitions were collected and buried by the local government into the two pits located in the Haerbaling area in Jiling Province, 43 km southeast of Dunhua City in China. Two third of the munitions are buried in Pit No.1 and the remaining one third are buried in Pit No.2. These pits are relatively small in size and the distance between two pits is about 65 meters.

The International Treaty of Chemical Weapons convention and the Memorandum of Understanding by GOJ and JOC regarding the abandoned chemical munitions in China call for recovery of abandoned munitions from the two burial pits. Accordingly, GOJ began its work to accomplish that objective. As Project Management consultants, we proposed and designed a telerobotic system that makes it possible to safely dispose of a huge amount of buried munitions efficiently and effectively. The system is designed to excavate buried munitions with maximum work efficiency while reducing the risk of munitions detonation and keeping exposure to chemical agents to the minimum level.

### 2. Munitions and their potential risks

According to the survey on the abandoned chemical munitions which have been excavated and recovered in China, more than 90% of munitions are expected to be small and light, and hence are relatively easy to handle with robotic systems. A breakdown of munitions by size and weight is shown in Table 1.

Diameter (mm)	Length (mm)	Weight per munition (kg)	Percentage in number (%)
75	302.5	5-6	22.4
90	392	5-6	70.9
105	485.5	16	4.9
150	556	32	1.8

Table-1 Sizes and weights of munitions

The breakdown by expected chemical agent types is shown in Table 2. As indicated, 88% are chemical munitions types and 12% are conventional non-chemical munitions types.

Chemical agent	Percentage in number
Mustard/Lewisite	60.4
Diphylcyanarsine	27.6
None (Conventional)	12.0

Table-2 Percentage of Chemical Munitions

In addition to the risks of explosion and exposure to chemical agent of the chemical munitions, the following specific risks were taken into consideration when planning the facilities for excavation and recovery.

- Sensitization of explosive by the composition of metal picrates.
- Unexploded munitions with fuse.
- Large scale explosion due to the sympathetic detonation.
- Dispersion of the chemical agents in an accident.
- Leakage of chemical agent from the munitions.

### 3. Basic Design Concept for Excavation and Recovery of Buried Ordnances

The basic design concepts of the excavation and recovery facilities are:

- ☛ To adopt a robotic system to minimize manual excavation work.
- ☛ To adopt a remote control system to ensure the safe excavation and recovery work
- ☛ To carry out the excavation and recovery work by people only for special cases when the use of a robotic system becomes inappropriate.

Even though a small number of abandoned chemical munitions in China have been excavated and recovered by people in the past, the robotic system can be utilized to remove munitions in Haerbaling safely and efficiently since a large amount of munitions is buried in a relatively small area. The shape of burial pits are inverted trapezoids and their sizes are as shown in Table-3.

	Length(m)	Width(m)	Hight(m)
No.1 Pit	25	12	6.5
No.2 Pit	18.5	10	4.4

Table-3 Sizes of pits

By applying high performance tele-robotic control to the robotic system, the excavation and recovery work becomes safer and more efficient, and can minimize

human errors and reduce potential risks.

Buildings will be constructed at each burial pit to keep leaked chemical agents from being scattered into the air, thus making the environmental condition suitable for excavation and recovery work with a robotic system. Two sets of the robotic system will be installed at Pit No.1 pit and one at Pit No.2. Munitions removed from the burial pit by the recovery robot will be transferred onto the auto-guided vehicle (AGV), which travels around the pit, and transported to the next facilities for classification, sorting, packing and storage. The recovery robots and AGV are to be controlled from the remote control center.

#### 4. Functions of Excavation System

The main functions of excavation system for recovering the buried munitions are

- ☛ To remove the soil around the munitions
- ☛ To pick up the munition from the burial pit and put it into the munition box
- ☛ To receive the empty munition boxes from the AGV and to discharge the loaded munition boxes onto AVG

To achieve the main function of excavation and recovery system, the excavation system should be composed of the soil removal system, excavation robot, and conveyor system. The munition box is used to transport the munitions with conveyor and AGV to be stable and safe.

#### 5. Soil removing

##### (a) Function

Originally, the abandoned chemical munitions likely were piled up in the big inverted trapezoid pit and then the pit was backfilled with soil. The covered soil of 2-3 m depth, will be removed by humans before starting the excavation work of buried munitions. The soil removing system should be able to remove the soil around the munitions without any harmful disturbance to the munitions, which have the potential risk of explosion due to shock to the munitions. The upper half of soil around the munitions will be removed by remote operation to the extent that the buried munitions can be visually confirmed through CCTV monitors and the buried munitions can be gripped with the excavation robot.

##### (b) Verification tests

The soil removal system is newly developed, because there is no past experience which is applicable to this project. The design conditions of soil removal system are as described below.

- ☛ Munitions are buried in the sandy soil of weathered granite.
- ☛ Munitions are randomly placed.
- ☛ Soil should be removed with a telerobotic system.
- ☛ Soil should be removed without applying any harmful shock on the munitions
- ☛ Soil should be removed to such an extent that types and positions of munitions can be recognized with the automatic sensing system and the munitions can be gripped with the excavation robot.

The suction-type soil removal system was selected to meet such conditions. The soil suction nozzle is composed of a compressed air injection nozzle and an air extraction nozzle. At first, the soil will be loosened by injecting compressed air, and then extracted through the air extraction nozzle.

Verification testing was conducted in the following sequential steps:

- ☛ Select suitable sandy soil having the same grain distribution as the one in Haerubaling.
- ☛ Compact the soil to simulate the same burial condition.
- ☛ Conduct fundamental testing under various conditions and decided on the construction of nozzle.

- ☛ Conduct total testing using mock-up munitions buried under various conditions.
- ☛ Examine the availability of water spray on the performance of soil removing.
- ☛ Confirm the performance of the collision avoidance system between the nozzle and munitions.

Using this test setup, the performance of the suction-type soil removal system was successfully demonstrated. Results of the test are described below.

- ☛ The combination of an injection nozzle and an extraction nozzle can be used to remove the sandy soil of weathered granite effectively. It is less effective for clay soil.
- ☛ The soil can be removed without any disturbance to or pressure on the buried munitions.
- ☛ A water spray of small quantity is effective to loosen the compacted soil and to make the soil removing more efficient.

#### (c) Soil removing machine

The soil removing system is composed of a soil extracting nozzle, a soil separator, a dust collector, a blower, hoses and pipes. The soil is extracted from the pit and discharged into the soil container in the machinery room.

The soil extracting nozzle and the hoses are fixed on the supporting arm, which is installed on a traveling bridge. The suction nozzle is gripped by the excavation robot during the soil removing operation and the soil extracting point are shifted by moving the suction nozzle with the excavation robot manipulator.

The collision avoidance system is provided to prevent the suction gripper from hitting the munitions in the pit.

### 6. Excavation

#### (a) Function

There are several key functions which have to be incorporated in the excavation robot to ensure safe, efficient and reliable operation and to make it practical and useful at the Haerubaling site.

##### ☛ Gentle handling during gripping operation

It is very important not to disturb the ambience of munitions or create shocks to the munitions during gripping operation, because of the potential risk to munitions with fuses and metal picrate which are very sensitive to shock.

##### ☛ Firm gripping of munition

It is also important that the munition, which is once picked up with gripper, should not be dropped onto the burial pit in order to avoid any impact to other munitions in the pit.

##### ☛ Easy gripping operation

The type and construction of the gripper should be suitable for telerobotic operation. This is because the telerobotic gripping operation is not as easy as it seems in general.

##### ☛ Exact sensing of the munitions

The exact sensing of location, direction and center of gravity of buried munitions should be done within a limited timeframe.

##### ☛ Rational combination of automatic and manual operation

Automatic operation combined with operator's judgment should be undertaken because we believe it is most reliable way to pick up the munitions safely and efficiently.

#### (b) Gripper

There is no past experience to pick up a large number of buried munitions within a limited timeframe, and existing telerobotic systems, which handle explosive ordnances, are not applicable to this project. Hence, the excavation robot should be

newly developed to fit this special case. For this purpose, two kinds of gripper hands have been selected and tested to confirm the functions needed by the gripper and to finalize its specification. The concept and test results of these two type of gripper are described below.

(1) Magnet with flexible gripper

The concept of this type is to integrate two different functions into one gripper to meet the requirements of adopting autonomous control, gentle handling, and reliability not to drop the munitions. The magnet is easiest way to pick up the object and accordingly easiest way to attain autonomous control. After picking up the munitions by the magnet, three fingers, which are activated by the motor and wire, will grasp the munitions gently to avoid dropping it during the shifting motion into the munitions box. It has been confirmed through the verification test that sufficient magnetic force can be attained with a reasonable size of magnet and the flexible gripper of three fingers can then grasp the munition gently and firmly. The requirements on accuracy for positioning magnet were also confirmed.

(2) Picking gripper

The picking gripper has been used in every industrial field including for explosive handling robots. The construction is simple and reliable. This type of gripper works to grip the munitions by remote control under the special burial conditions. Two types of picking gripper were tested to determine the best mechanism, shape of gripping finger and gripping procedure for each type of munition. One is a rigid type, which is more suitable for gripping the larger munitions, and another is a flexible type, which is more suitable for gripping the smaller munitions. It has been confirmed that both types of grippers could grip the munitions firmly. The disadvantage of the gripper is that ambient disturbance on munitions could not be avoided and the high accuracy of positioning, which is not easy to attain through automatic and manual operation, are required during picking operation.

(3) Suction gripper

The magnet gripper was the best selection, because the positioning of gripper on a buried munition is easy, the disturbance to ambient munitions can be minimized, and the munitions can be lifted up gently. However, the magnetic type could not be selected since there is a slight possibility of the magnet inadvertently creating induced electrical current in the proximity of a fuse, which in turn may cause munitions to explode. (The proximity fuse was not developed by the old Japanese army, but still there is a slight possibility of foreign-made proximity fuse being buried in the pits.)

The suction gripper is the alternative, which has the same advantages as magnet gripper. The suction gripper is widely used in the industrial field to pick up handling material, and many kinds of suction pads are commercially available. However, none of them are applicable for rusty munitions with soil adhered. The verification testing was carried out to develop a suction pad, which is applicable for buried munitions, and to confirm its effectiveness under various conditions. The vacuum for suction gripper was created with compressed air and ejector.

The test results are as follows:

☛ The closed cell formed spongy was suitable for suction pad. (The bellows type suction pad is not applicable.)

☛ The suction gripper could lift a rusty shell, with soil adhered, and with a groove.

(4) Selected gripper

The suction pad with three-fingers with two knuckles is our final selection as the gripper for excavation robot. The munition is first picked up with suction pad

and lifted slightly, and then gripped with the three fingers with two knuckles. The three fingers with two knuckles grip the munition with six contact points which withstand the gravity force of munitions and moment force due to the difference of center of gravity of munition and center of gripping hand. The advantages of suction gripper are to minimize the ambient disturbance on the munitions and easy positioning of gripper onto the munition to be picked up. The advantage of three-fingers with two knuckles is to grip the munition gently and tightly with reasonable gripping force. These advantages enable the automatic and/or semi-automatic operation of excavation robot which leads to the safe, reliable and efficient excavation work of buried munitions.

(c) Exact sensing of munitions

The exact sensing of the location of munitions is another key element of this tele-robotic system for excavation work. The data of location of buried munition is needed to shift and position the gripper onto the munition to be picked up automatically and accurately. The stereo vision system or laser scanner is used to take the digital data and to get the 3D image of buried munitions within a short period of time. The 3D image data is further processed by the image recognition program and the munitions are discriminated and classified by size. The data of location, direction and position of center of gravity of the munition is generated and used to control the gripper and the manipulator.

(d) Rational combination of automatic and manual operation

We don't believe that most of the munitions can be excavated only by automatic operation or most of the munitions can only be excavated safely and efficiently by manual operation. Rather, automatic operation combined with operator's judgment should be undertaken because we believe it is the most reliable way to pick up the munitions safely and efficiently. The operation sequence is as follows:

- (1) The 3D image is displayed on the screen of operating panel.
- (2) If the discrimination is erroneous, operator can correct it on the screen.
- (3) Operator selects the munition to be picked up by touching the screen or by using the mouse.
- (4) The data of location, direction and position of center of gravity of the munition is generated and used to control the gripper and the manipulator.
- (5) When operator pushes the start button, the gripper is shifted and stopped automatically above the munitions to be picked up. The gripper and finger are suitably positioned automatically.
- (6) After confirming the correctness of the position of the gripper through the video image and/or 3D image, the operator pushes a button to start the automatic gripping operation. Operator is watching the video image during the gripping operation, and can interrupt at any time and can operate the excavation robot by remote manual control mode if necessary.
- (7) After gripping the munition, it is automatically lifted up and placed into the munitions box.
- (8) The gripper returns to the original position automatically.
- (9) Repeating of operations (3) to (8).
- (10) The collision avoidance system is always working during the operation.

7. Conclusion

As the result of the experiments, a useful database had been obtained for the design of the gripping hand and the soil removal system. We will continue to work on validation of the total system of excavation robot by using the mock-up machine to enable the excavation operation by the telerobotic system. Through these tests and validations, we believe we can develop a safe, reliable and efficient robotic system that can be used for

the recovery of abandoned munitions from the two burial pits in the Haerbaling area of Dunhua in Jiling Province, China.