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Houdini: Reconfigurable In-Tank Robot

Authors:

David W. White
Adam D. Slifko
Bruce R. Thompson
Chester G. Fisher

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Contractor:

RedZone Robotics, Inc.
2425 Liberty Avenue
Pittsburgh, Pennsylvania 15222

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David W. White (dwhite@redzone.com; 412-765-3064)
Adam D. Slifko (aslifko@redzone.com; 412-765-3064)
Bruce R. Thompson (brt@redzone.com; 412-765-3064)
Chester G. Fisher (fisherc@redzone.com; 412-765-3064)
RedZone Robotics, Inc.
2425 Liberty Ave.
Pittsburgh, PA 15222

Introduction/Needs

RedZone Robotics, Inc. and Carnegie Mellon University (CMU) are developing a tethered mobile robot, Houdini, to work inside waste storage tanks in support of the Department of Energy's Environmental Restoration and Waste Management (EM) Program. This project is funded by the DOE's Environmental Management Office of Technology Development through the Morgantown Energy Technology Center (METC). Our goal is to develop technology that is useful for in-tank operations throughout the DOE's EM program.

The first application of the Houdini system is to support the waste retrieval action planned for the final remediation of the Fernald site's waste silos. RedZone and CMU have discussed potential applications for the system with personnel from several other DOE sites, and have found that the system would be widely useful in the DOE complex for tasks both inside and outside of waste storage tanks. We are tailoring the first implementation of the Houdini system to the specific needs of the Fernald silo remediation. The Fernald application-specific design constraints are primarily interface issues and should not interfere with the utility of the system at other sites.

In addition, DOE personnel at the Oak Ridge National Laboratories (ORNL) have expressed a strong interest in the Houdini system. They have a target application scheduled for mid-1996. This program represents a unique opportunity to develop a new technology that has immediate application in two CERCLA cleanup actions; the proposed applications at Fernald and ORNL support Federal Facility compliance agreements.

Objectives/Problem

The primary application for the Houdini system is to support the final remediation of Silos 1, 2, & 3 at the Fernald Site. Houdini will perform essential missions in support of this final remediation effort that will retrieve waste from the tanks and vitrify it for long term storage.

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The CRU4 area at the Fernald site contains 4 above-ground, concrete waste silos. All four domed waste silos are 24.4 meters (80 feet) in diameter, 11 meters (36 feet) high at the center of the dome, with 8.3 meter (27 foot) high vertical walls. Four 0.51 meter (20 inch) diameter manways are evenly distributed around each tank dome at 15 feet from the side walls, at a slant of 17 degrees from horizontal. A fifth 20 inch manway near the center of the dome will be eliminated when a 6 foot opening is created to support the remediation activity.

Some structural deterioration has been noted in the walls and domes of the silos, resulting in load restrictions. No detectable load is allowed on the 6.1 meter (20 foot) diameter center section of the dome. On other dome areas, the maximum live load is limited to 700 pounds including personnel and gear.

Waste material in Silos 1 and 2 is described as K-65 material and has the consistency of toothpaste. The waste is covered with a 0.3 meter (12 inch) thick layer of Bentonite clay to reduce radon emissions from the waste. Material in Silo 3 is a light, dry metal oxide powder similar in consistency to talcum powder. The Silo 3 waste may be compacted near the bottom of the silo. In addition, each silo contains pipes, wrenches, sample bottles, gloves, and other debris that has fallen into the tanks over the years.

The fourth silo is identical to the other three, but was never used for waste storage. It will be used as an uncontaminated mock-up facility to fully test all procedures prior to remediation of other silos. Silo 4 may be partially filled with a surrogate waste material to support these tests.

To enable the waste retrieval operations in light of the dome load restrictions, a superstructure has been constructed over Silo 4. An equipment room situated over the center of the dome is supported by the superstructure. Seals will be installed between the equipment room and the silo dome and a six foot diameter opening will be made in the silo dome directly under the equipment room. Doors in the equipment room floor will provide access to the tank. Controlled entry points, rails, winches, equipment carts, and other mechanisms in the equipment room will support the deployment and retrieval of equipment into the silo.

The primary retrieval method for Silo 1 and 2 waste will be hydraulic removal. A sluicing pump will be lowered into the tank from the equipment room. Water will be added to the waste material and the liquefied waste will be pumped out of the tank. In Silo 3, pneumatic conveyance will be used to retrieve the waste material. The methods will remove the bulk of the waste materials from the tanks, leaving only debris and a waste heel to be removed by other means.

Approach/Solution

The Houdini system will be used for heel and debris removal from the tanks, during and after the bulk material removal by sluicing and pneumatic conveyance. In Silo 4, Houdini's capabilities will be fully tested in an uncontaminated environment. The silo will be partially filled with surrogate waste material and debris that approximates the waste properties in Silos 1 and 2. During bulk material removal, Houdini will be deployed to remove debris material that interferes with the sluicing operation. Using a shearing tool and gripper, Houdini would be deployed to gather debris, size reduce the debris as necessary, and load the debris into a tram bucket for retrieval from the tank. After the bulk waste removal action is complete, Houdini will be deployed to perform waste heel removal and debris collection. To perform the heel removal, a small sluicing pump will be lowered into the tank. Houdini will use its gripper to deploy a water spray nozzle. Water spray will be used to mobilize the heel material and wash it toward the sluicing pump for removal. The Houdini plow blade will be equipped with squeegees on the sides and bottom and will be used to push slurried waste material toward the sluicing pump. The edge of the plow blade can be used to push waste material away from the side wall of the tank to clean the edges of the tank floor. Houdini can also be used to wash down or apply a spray coating to the tank side walls for decontamination.

In Silos 1 and 2, Houdini will be used to support waste retrieval for final remediation in the same modes as described above for the Silo 4 functional test. The radioactive waste in Silos 1 and 2 will be primarily retrieved by sluicing, after which, the waste will be vitrified for long term storage.

In Silo 3, Houdini will support waste retrieval for final remediation in conjunction with the bulk material removal by pneumatic conveyance. Specifically, Houdini will perform debris collection, size reduction, and removal during and after bulk pneumatic conveyance, and perform heel removal by deploying a pneumatic vacuum hose. In addition, Houdini could be used to plow waste material to a central point for pneumatic retrieval. Houdini could also deploy tools to assist in removing compacted waste material from the tank floor.

Project Description/Technology

System Overview

The Houdini system consists of five main components and their subsystems; the vehicle, deployment system, PDCU, control consoles, and tooling.

Vehicle. The vehicle is a hydraulically-powered, track-driven, folding frame machine similar to a small bulldozer. The vehicle can fold to fit through a 0.57 meter (22.5 inch) diameter opening for deployment, and is equipped with a plow blade and a manipulator arm. The plow blade also folds for deployment and can be height-adjusted for plowing various materials at various rates. The manipulator is a Schilling Titan class hydraulic dexterous manipulator, which can deploy a variety of tooling for performing work inside a tank. The vehicle tether is attached to the rear of the folding frame assembly. The tether termination will support the full weight of the vehicle and tooling to enable deployment and retrieval. Two camera and light assemblies provide visual feedback for remote operation. One camera and light unit is mounted on the forearm of the manipulator. The camera is aimed by orienting the manipulator. The second camera unit includes a pan and tilt unit and is mounted on a mast at the manipulator shoulder. A microphone will provide audio feedback to the operator. Navigation system sensors will be installed on the vehicle as part of the navigation system interface.

Deployment System. The deployment system is designed to interface with the superstructure and equipment room above the Fernald waste silos. It is an important part of the Houdini system. First, it provides a convenient way to remotely manage and store the 150 feet of tether that is the lifeline of the Houdini vehicle. Second, it provides the lifting force that is needed to lower and raise the vehicle into and from the tank. Third, it provides a "docking area" where the vehicle can be secured during storage or transport, and lastly, it provides an area where spare parts or tools can be stored when not in use.

Tether Reel. The tether reel is a "spool" looking device that is 48 inches in diameter and 30 inches wide. A flange at each end contains the tether on the drum. Payout of the tether is controlled by a mechanical level-wind system that ensure that the tether does not cross over on itself and tangle. The tether reel is driven by a hydraulic motor with a "power-off" brake in case of hydraulic power loss. The hydraulic motor is sized to allow a pull force of 2000 lb tangent to the reel surface. A payout sensor is used to monitor the length of tether that has been reeled out. The sensor shall also indicate ends of travel (i.e., when the tether is completely in or out). A means of manual retrieval is necessary in case of hydraulic power failure. This is accomplished with an external, battery powered, hydraulic supply and manually operated valve.

Tether. The tether is used to lower and raise the vehicle in the tank and provides control signals and electric and hydraulic power to the vehicle. The tether will be a custom fabrication that includes:

- Strain-relief termination
- Hydraulic supply and return lines
- Shielded-twisted pairs for control and feedback signals
- Mini-coax lines for camera signals
- Shielded-twisted pairs for navigation system signals
- Conductors for power to onboard valving
- Kevlar braid for structural support (to carry the weight of the vehicle)
- Abrasion resistant coating

Power Distribution and Control Unit. An environmentally sealed and temperature controlled power distribution and control unit (PDCU) will be installed on the superstructure, outside the equipment room. The PDCU includes the electric transformers and distribution/conditioning equipment, the control system, and tether and control system interface connectors. A separate enclosure will house the electrically-powered hydraulic power supply.

Control Console. The operator console provides the operator interface to the Houdini system. The console includes joysticks, switches, a master manipulator, and video monitors for controlling system functions and monitoring system operation.

Navigation System Interface. An interface will be provided to the Position and Orientation Tracking System (POTS) which has been developed at ORNL. ORNL has agreed to make POTS available to this program as Government-Furnished Equipment. POTS will provide accurate feedback on the vehicle's position and orientation inside a tank to enable more efficient and robust controls.

Control Trailer. A control trailer will house the operator control console. The trailer will be a simple mobile, industrial trailer that provides heated and air conditioned real estate for the operator. Tie downs will be provided for securing the trailer against high wind. The trailer will be structurally capable of being moved with the control console inside. The trailer will require 110 volt site power.

Suitcase Controller. A hard-wired suitcase controller will be available to perform system checkout, local operations and provide for emergency operations in the case of console/control computer or telemetry failures between the control center and the deployment system. Switches, buttons, and a single remote viewing monitor will provide for simple operations from the suitcase controller.

Tooling. Specialized tooling will be provided to enable the use of the Houdini system in support of the Fernald waste retrieval plans. The bottom and sides of the plow will be equipped with squeegee blades to provide efficient mobilization of the waste slurry on the floor of the tank. A gripper, shear, and scoop will be provided for deployment from the manipulator. For sluicing operations, Fernald will provide a small pump for heel removal operations; RedZone will equip the pump with a water line, hose reel, and spray nozzle that can be deployed by the Houdini manipulator to spray-wash waste material toward the sluicing pump. For vacuum retrieval operations, Fernald has agreed to provide a hose grip that will attach to the manipulator and enable the deployment of a pneumatic vacuum hose.

Application/Benefits

As a technology for supporting the DOE's EM program and in comparison or collaboration with other competing technologies, Houdini provides many benefits. The Houdini system is designed to eliminate or reduce potential public and operational health risks associated with work on DOE tanks. The system provides fully-contained remote operation, reducing the risk of spreading contamination outside of the tanks. Because of Houdini's similarity to bulldozers and backhoes from the construction industry, it provides simple, intuitive, and efficient waste handling techniques. Houdini's transportation, installation, deployment, and removal operations are simple due to its compact size. Houdini's simplicity and operational capability lead to cost efficiency with respect to development, operation, and maintenance.

Evaluating the merits of the Houdini system for these applications requires comparing it to competing technologies. In comparison to mobile robot systems that are currently available, Houdini's folding frame technology provides a substantially larger work platform which can fit through existing tank openings. As a larger platform, Houdini is more powerful, more efficient, and more capable than other, smaller mobile systems.

Several non-robotic retrieval methods are being considered for use in DOE tanks. These technologies, such as sluicing, pumping, and pneumatic conveyance, are appropriate or preferred technologies for some of the tanks in the complex. As it will at Fernald, Houdini could assist in the application of these retrieval and conveyance methods. In addition, the current design could be applied for use in Oak Ridge's north and south tank farms.

Depending on specific work tasks and application sites, Houdini can be deployed to either complement or replace a long-reach manipulator (LRM) system. Used in conjunction with LRMs, Houdini provides additional or enhanced capabilities inside a tank. In tasks where Houdini is useful instead of LRMs, Houdini will be simpler and less expensive to deploy, operate, retrieve, and decontaminate than LRMs.

Future Activities/Applications

In addition to the primary application at Fernald, other applications for Houdini have been identified in support of tank waste retrieval operations in the DOE and private sector. Also, several tasks outside of tanks have been identified for which Houdini would be useful.

Oak Ridge North and South Tank Farms

The north and south tank farms at Oak Ridge National Laboratory have a total of 16 domed, cylindrical, single-shelled, underground storage tanks made of Gunite (similar to concrete), ranging in diameter from 20 to 50 feet and equipped with 24 inch diameter manway penetrations. These tanks were used to store laboratory waste and are expected to contain a wide variety of materials, with estimated radiation levels of 1 to 100 R. During 1983-1984 the tanks were emptied through a sluicing method, leaving a heel of up to several feet thick at the bottom. The heel waste must be removed to prevent the migration of waste material out of the tanks. ORNL is under a Federal Facility Compliance Agreement to complete a CERCLA treatability study on the Gunite and associated tanks. The baseline plan for this study includes the evaluation of both vehicle- and arm-based retrieval systems. The current plan at ORNL is to evaluate the Houdini vehicle during this study, and if successful, Houdini might be selected for the final remediation retrieval action.

Other DOE Tank Applications

The Houdini system is useful in a variety of other DOE tank waste retrieval operations. Houdini could be deployed in a tank prior to the major removal action to collect additional information about the waste content and tank interior.

In support of other in-tank work systems, such as long reach manipulators, Houdini could be used to deploy cameras, lights, and sensor systems. The mobile deployment of such monitoring equipment will provide viewing and data gathering flexibility that cannot be achieved by mounting such equipment on fixed masts or on a long reach manipulator.

The long reach manipulator (LRM) systems that are being developed for tank waste retrieval will require a variety of tools to accomplish their tasks. The Houdini crawler could serve as a mobile tool carrier for the LRM, carrying several tools and making them available at the most appropriate location inside the tank.

In support of final tank decontamination and decommissioning, Houdini could deploy tools to scarify internal tank surfaces.

Commercial Tank Applications

Periodic cleaning and inspection of storage tanks in petro-chemical industries are becoming common maintenance procedures. It is likely that these procedures will be required by law in the US in the next few years. We have been in contact with several service providers in the petro-chemical industry, who have expressed an interest in the Houdini system in support of these operations.

Non Tank Applications

Alternate uses currently envisioned for this system include indoor as well as outdoor tasks. In support of buried-waste excavation programs, Houdini could perform fine excavation and monitoring to assist a larger remote excavator, perform fine excavation to isolate and extract specific objects, and assist removing a drum in one piece. In support of decontamination and dismantling programs, Houdini could be used as a small platform to gain access through tight areas for selective equipment removal and could lend assistance to larger worksystems as a tool-carrier platform, size-reduction system, or waste packaging system. In support of surveillance and monitoring operations, it could perform such functions as monitoring drum storage areas and decommissioned processing areas requiring access to tight corridors. Removal of the tether is possible through the use of a gas-engine or batteries and the interface of a radio telemetry system.

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Vijendra Kothari
Project Manager
U.S. Department of Energy
Morgantown Energy Technology Center
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
(304) 291-4579

Bruce Thompson
Project Manager
RedZone Robotics, Inc.
2425 Liberty Ave.
Pittsburgh, PA 15222
(412)-765-3064

Hagen Schempf
Principal Investigator
Carnegie Mellon University
Building C-Field Robotics Center
5000 Forbes Ave.
Pittsburgh, PA 15213
(412)-268-6884

Brack Hazen
FERMCO
PO Box 398704
Cincinnati, OH 45239
(513)-648-6554