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Houdini^{TM}: A Remote Mobile Platform for Tank Waste Retrieval Tasks

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HOUDINI™
A REMOTE MOBILE PLATFORM FOR TANK WASTE RETRIEVAL TASKS

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ABSTRACT

RedZone has developed Houdini™: a folding frame vehicle for work in waste storage tanks and other confined-access areas. Houdini is a tethered, hydraulically-powered platform that folds to fit through small openings. Once deployed, the vehicle unfolds to provide a substantial work platform for the deployment of a wide variety of tools. The Houdini system will perform heel removal, waste retrieval, waste mobilization, waste size reduction, and other tank waste retrieval and decommissioning tasks. Within the DOE Complex, 332 underground storage tanks have been used to process and store radioactive and chemical mixed waste generated from weapon materials production. The ultimate goal of the program is to develop and commercialize the Houdini system for broad application throughout the DOE Complex.

INTRODUCTION

In March of 1997, through unwavering commitment from the Environmental Management Office of Technology Development, the aggressive integration skills of Oak Ridge National Laboratory and the focused execution of RedZone Robotics, Inc., the Houdini™ reconfigurable vehicle will become the first robotic system to be deployed in a hot underground storage tank within the DOE Complex. This unprecedented trailblazing deployment will not only validate the feasibility of vehicle based in-tank waste retrieval, but more importantly establishes a significant benchmark for the robotics community in the high level waste tank clean-up application.

RedZone Robotics, Inc., in conjunction with Carnegie Mellon University (CMU) has completed the fabrication and testing of an innovative remote mobile vehicle platform to work inside waste storage tanks in support of the Department of Energy's (DOE) Environmental Restoration and Waste Management (EM) Program. The Houdini system will perform heel removal, waste retrieval, waste mobilization, waste size reduction, and other tank waste retrieval and decommissioning tasks. The project is funded by the DOE’s Environmental Management Office of Technology Development through the Morgantown Energy Technology Center (METC). While originally tailored to the specific needs of the Oak Ridge and Fernald applications, the goal of the Houdini project was to develop a technology that would be useful for in-tank operations throughout the DOE’s EM program.

OBJECTIVES

Within the DOE Complex, 332 underground storage tanks have been used to process and store radioactive and chemical mixed waste generated from weapon materials production. Together, these tanks hold more than 100 million gallons of high-level and low-level radioactive waste, very little of which has been treated and disposed of in final form.

The first application of the Houdini system is to support the waste retrieval action planned for the final remediation of the Oak Ridge National Laboratory (ORNL) Gunite storage tanks. ORNL is preparing to demonstrate and evaluate a vehicle based approach for the remote retrieval of wastes in underground storage tanks. System requirements are based on the need to dislodge and remove sludge wastes ranging in consistency from broth to compacted clay. The second application of the Houdini system is to support the final remediation of Silos 1, 2, and 3 at the Fernald Site. The Houdini system will be used for heel and debris removal from the silos, during and after the bulk material removal.

The ultimate goal of the program is to develop and commercialize the Houdini system for broad application throughout the DOE Complex. Each system module is available separately and can be customized to meet the requirements of specific tank and non-tank applications at Oak Ridge, Fernald, Hanford, Savannah River, Idaho, West Valley and other sites. Likewise, the Houdini system supports commercial applications in the private sector.

APPROACH (Oak Ridge and Fernald Applications)

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 known as the Gunite and Associated Tanks (GAAT), ranging in diameter from 20 to 50 feet and equipped with 24 inch diameter accessways. 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/hr. During 1983-1984 the tanks were emptied through a sluicing method, leaving a heel of soft sludge generally 0.15 – 0.2 m (6 –8 in.) deep The heel waste must be removed to prevent the migration of waste material out of the tanks.

A treatability study has been undertaken at ORNL to evaluate waste removal and treatment technologies prior to final remediation activity. Houdini and other remote equipment will be used during this study to retrieve heel material from tanks in the North tank farm.

Fernald

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 accessways 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 accessway near the center of the dome will be eliminated when a 6 foot opening is created to support the remediation activity.

Waste material in Silos 1 and 2 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 been deposited into the tanks over the years.

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.

Plans for the Houdini system include support of 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.

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.

TECHNOLOGY DESCRIPTION

The Houdini system consists of five main components and their subsystems; the vehicle, PDCU, control consoles, tooling, and deployment system. Once deployed, Houdini expands to provide a powerful work platform with a substantial footprint (40 inches x 55 inches). Rugged design and sturdy construction make it well-suited for the rigors of waste mobilization and other heavy work tasks. Houdini also provides simple, familiar material handling similar to conventional earth-moving equipment such as bulldozers and backhoes. Houdini is a reliable, cost effective work platform that achieves performance objectives with minimal risk.

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. Controlled by an operator who sits at a console outside the work area, Houdini provides ample feedback from the work area via multiple cameras, microphones and instrumentation that reports equipment status. 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, mounted at the rear corner of the vehicle, includes a pan and tilt unit.

Power Distribution and Control Unit

An environmentally sealed and temperature controlled power distribution and control unit (PDCU) includes the electric transformers and distribution/conditioning equipment, the control system, and tether and control system interface connectors.

Control Console

The control 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. The control console incorporates ergonomic design considerations for long duration operation. A hard-wired suitcase controller is 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 PDCU. Switches, buttons, and a single remote viewing monitor provides for simple operations from the suitcase controller.

Navigation System Interface

An interface is 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.

Tether Management and Deployment System (TMADS)

Design of the deployment system for Houdini is dependent on the application in which it will be used. However, there are several functions for the deployment system that are common despite varying design. Regardless of the application, the deployment system provides a convenient way to remotely manage and store Houdini's tether, provides the lifting force needed to lower and raise the vehicle to and from a tank, provides a "docking area" for securing the vehicle during storage or transport, and provides a storage area for tools and spare parts. The deployment system also provides containment when open to the tank atmosphere.

The tether reel is 48 inches in diameter and 30 inches wide. Payout of the tether is controlled by a mechanical level-wind system that precludes tether entanglement during deployment and retrieval operations. 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 3000 lb. A payout sensor is used to monitor the length of tether that has been reeled out.

Tooling

Specialized tooling can be deployed from the onboard manipulator or plow blade, depending on application needs. Plans for the Fernald application include squeegees located along the plow blade to provide efficient mobilization of the waste slurry on the floor of the tank. A multitude of accessory tooling, such as shears, scoops or spray wands can be integrated for deployment from the manipulator. For vacuum retrieval operations, Fernald will provide a hose grip that will attach to the Houdini manipulator and enable the deployment of a pneumatic vacuum hose. The primary tool for the ORNL retrieval campaign is a waste dislodging and conveyance end effector which will be deployed and moved throughout the waste tank using the Houdini platform.

DEMONSTRATED RESULTS

Deployment Issues

A critical and absolutely essential requirement of the Houdini system is that it be capable of deploying and retrieving through the 24 inch riser in a reliable manner. This is in part driven by the desire to reduce radiation exposure to the vehicle by storing the vehicle in TMADS when not performing waste retrieval activities, but even more so by the need to decontaminate the vehicle after a typical work shift to prevent the hardening and build-up of waste on the vehicle.

Although the vehicle has been designed to fit through a 22.5 inch opening, the operational challenge is to get the vehicle started into the riser opening when it is not centered over/under the riser. For deployment, this is a matter of using the manipulator to guide the vehicle into the riser, then taking advantage of the funnel style lead-in provided by ORNL's riser sleeve to guide the body of the vehicle into the riser. Landing on the tank floor has proven to be simple and reliable. This is accomplished by using the manipulator and plow blade for initial touch-down and as pivot points. As the vehicle is lowered, it pivots down into a horizontal orientation and lands on the bottom of its tracks. For retrieval, guides were mounted at the back, top, and underside of the vehicle that serve as bumpers to guide the vehicle safely into the riser opening. Deployment and retrieval was demonstrated successfully at RedZone and will be repeated during cold testing at ORNL.

Vehicle Mobility Issues

An early vehicle design consideration was the effect of tether size on the traction and mobility of the vehicle. The tether is 2.7 inches (68.5mm) in diameter with a 24 inch (610mm) bend radius and weighs 2.4 lb/ft (3.57 kg/m) and imparts large side loads on the vehicle which are addressed by steering and control familiarity by the operator. In short, there are no mobility limitations caused by a tether. The vehicle has more than enough traction and push/pull/turn force so that the effects of a tethered vehicle go unnoticed. In fact, the stiffness of the tether has aided in operations to the extent that the operator does not have to worry about running over the vehicle's tether during turns and reversing scenarios because the tether is forced out of the way due to its own stiffness.

Other aspects of mobility such as speed control, traction, turning ability, slope climbing, and tip over have been tested. Houdini has proven to be highly controllable via dual joystick, infinitely variable speed control from 0 ft/sec (0 m/s) to a maximum speed currently set at approximately 1.2 ft/sec (.37 m/s). Houdini is capable of driving in the folded configuration. In a deployed/open configuration, Houdini can turn within its own length and can plow with up to 650 lbf (295 kg) on clean dry concrete. Depending on manipulator and payload position, Houdini can climb up a 35° ramp and will remain stable even on a 45° slope. Houdini has proven to be the stable work platform that it was intended to be.

Vehicle Performance

Vehicle performance inside the tank environment is largely a function of the waste material, its water content, and the resulting vehicle mobility on this waste. After system testing at RedZone in surrogate waste that is representative of waste found in the underground tanks at ORNL, we can make some qualitative statements concerning vehicle performance. The surrogate was a mixture of kaolin clay, sand, and water mixed roughly to the consistency of wet cement and varied from 8 to 16 inches deep. Operating in this environment, the vehicle was able to mobilize waste effectively. Using the front mounted plow, we could easily push the surrogate to a centralized pumping area. The plow is equipped with a squeegee on the bottom edge of the plow which left the tank floor virtually clean and dry. The plow performed equally well in reverse where it was used to pull waste away from the edge of the tank wall.

In addition to plowing successfully, the vehicle's manipulator was used to acquire and deploy a hydraulic shear that was lowered into the tank separately. Using the manipulator, the jaws of the shear were remotely positioned around a piece of 1/2 inch conduit and size reduced the piece into roughly 12 inch long sections. The manipulator also was effective in locating, retrieving, and placing unpumpables, ranging form heavy cinder blocks to light plastic bags, into a barrel for subsequent retrieval.

Houdini is equipped with two onboard cameras. One is hard mounted at the manipulator gripper and the other is mounted to a pan/tilt unit at the rear of the vehicle. At the test facility at RedZone, we had one fixed overview camera available to aid in remote operations. Using the onboard cameras and the limited overview camera we were able to perform all testing and operation of the vehicle remotely. In a true tank deployment, one would expect several overview cameras with pan/tilt/zoom control which will only make remote operation simpler. During operation inside the tank it is expected that cameras will become obscured by waste that may get splashed onto camera lenses. Houdini has a camera lens cleaning system that sprays the camera housing lens with water followed by air for drying. This method of cleaning is initiated by the press of a button and was demonstrated successfully.

<u>Operator Efficiency/Effectiveness Issues</u>
During testing, several ORNL operators visited RedZone to become familiar with the system and to log operating time at the console. Operators reported that the system was easy to learn and adjust to. The dual joystick control (one for each track) was very intuitive as were the easily accessible joystick mounted controls for the plow blade, tether control, and camera cleaning system. The operators were driving the vehicle effectively in less than and hour. Most training time was spent mastering the control of the vehicle mounted manipulator. The system is enhanced through the addition of foot pedal controls as an alternative to the joysticks. The operator can keep his hands free to operate the manipulator and cameras while using his feet to make adjustments to the vehicle position.

Vehicle decontamination at RedZone could only be demonstrated manually through the use of a regular garden hose. While decontamination of a vehicle based system is expected to be difficult, some encouraging results were achieved. Through manual washdown we were able to remove approximately 95% of surrogate material that was stuck to the vehicle. Several approaches can be taken towards decontamination. The first approach is the use of a high pressure spray ring. If areas of the vehicle are not effectively cleaned by this means, then a spray wand mounted inside of TMADS can be used to manually reach the difficult areas. As an alternative to manual washdown, a technique of self washdown using the vehicle's manipulator was tried with some success. In this scenario, a spray hose is lowered to the vehicle while in the hanging and open position. The manipulator then grasps the spray nozzle and performs a self washdown by pointing the nozzle at the difficult to reach areas.

Routine vehicle maintenance can be performed inside TMADS. This would include the change-out of the vehicle mounted cameras and lights, tread replacement, and onboard hydraulic valve replacement. Other maintenance activities will require the vehicle to be removed from TMADS and the vehicle frame opened. More detail on the maintenance requirements will be learned and demonstrated during cold testing at ORNL.

BENEFITS

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 also being planned for use in various 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 and ORNL, Houdini could assist in the application of these retrieval and conveyance methods.

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.

As a technology for supporting the DOE's EM program and in comparison or collaboration with other competing technologies, Houdini provides many benefits. 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.

FUTURE ACTIVITIES

In addition to the planned activities at ORNL and 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.

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 considered 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 an 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. The cleaning tasks for these tanks involves the removal of thick sludge material from the tank floor. Houdini and other DOE-developed technologies are applicable to these commercial tank cleaning opportunities

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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