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PRELIMINARY EVALUATION OF THE ACCIDENT RESPONSE MOBILE MANIPULATION SYSTEM FOR ACCIDENT SITE SALVAGE OPERATIONS[†]

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ABSTRACT

This paper describes and evaluates operational experiences with the Accident Response Mobile Manipulation System (ARMMS) during simulated accident site salvage operations which might involve nuclear weapons. The ARMMS is based upon a teleoperated HMMWV mobility platform with two Schilling Titan 7F Manipulators.

INTRODUCTION

The need for a telerobotic vehicle with integral manipulation capabilities has been identified for use in transportation accidents, where nuclear weapons are involved. Realistic accident scenarios of this type are highly unstructured. They may engage terrain requiring significant vehicle mobility to reach the accident site and require ample vehicle payload. Although there are Unmanned Ground Vehicles (UGV) with integral manipulation, none exist with the desired off road stability and payload capabilities in conjunction with the high-strength manipulation necessary to perform anticipated salvage and recovery operations at hazardous accident sites.

The ARMMS (Accident Response Mobile Manipulation System) platform has been developed at Sandia National Laboratories' Robotic Vehicle Range [1] in support of the Accident Response Group (ARG). ARMMS primary mission will be to support ARG salvage operations, which has driven the design to place strategic emphasis on reliability and maintainability. The ARMMS base vehicle is a HMMWV fully actuated for teleoperation. ARMMS is equipped with two high strength hydraulically actuated Schilling Titan 7F manipulators and is capable of utilizing the ARG Portable Integrated Video System (PIVS) [2].

Documented field or laboratory experience using multiple manipulators on an UGV mobility platform is extremely scarce [3]. Preliminary efforts to study and characterize the capabilities and limitations of the ARMMS platform at an accident site, in its present configuration, are discussed in this paper [4].

CHARACTERIZATION TASKS

Five experimental tasks were established for this preliminary study to characterize the present capabilities of the ARMMS platform: (1) lifting and removal of a piece of F-4 fuselage wreckage; (2) retrieval and packaging of an unknown simulated generic bomb sphere; (3) vertical uprighting of a 770 lb. W80

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DISCLAIMER

shipping container; (4) laying horizontal a W80 shipping container; (5) lifting a W80 shipping container. Seven experimental subjects were selected to achieve as representative of a sample as possible. The subjects included four males and three females ranging in age from 22 to 52 with occupational backgrounds in engineering, administration, and fine arts. Only one subject had prior significant experience with the ARMMS platform. Tasks and environmental variables were not varied during this initial study. Performance measures included: task completion time; number of attempts to complete a task; and number of arms used to accomplish a task. A questionnaire was used to obtain subjective data from the test subjects.

TEST CONFIGURATION

All testing was conducted at Sandia National Laboratories' Robotic Vehicle Range shown in Figure 2. The test setup, shown in Figure 3, included a 770 lb. W80 shipping container, an F-4 wing fuselage segment, and a stainless steel spherical pressure vessel to simulate a generic bomb. The Schilling Titan 7F manipulators were configured on the HMMWV's stern. The Schilling Titan 7F spatially-correspondent master controller [6] was used for all experimentation presented in this paper. Completed testing to date was limited to operations which provided direct visual and audio feedback. The test configuration in conjunction with the selected tasks is intended to serve as a baseline for evaluating the "goodness" of the present system and future enhancements.

PERFORMANCE RESULTS

A summary of performance measurement results is graphically illustrated in Figure 1. Discussion of the tasks and associated results is provided.

Wing Removal

A simulated generic bomb was placed under a section of bulky aircraft fuselage. The task of removing the fuselage without the use of any equipment would require two people wearing appropriate protective clothing. However, this same task was able to be completed by a single person using the ARMMS platform. This task required moderate finesse in the gripping and lifting of the bulky fuselage segment in order to move it out of the way and gain access to the simulated bomb underneath. Average completion time among the test subjects was 1.6 minutes with very little deviation between the operators. The shortest task completion time was 30 seconds; the longest was 1.7 minutes. All operators were successful on their first attempt and used only a single arm.

Simulated Bomb Manipulation

A simulated generic spherical bomb with a stub-out tube was used to test manipulation dexterity. The task of picking up the simulated bomb without the use of any equipment can easily be accomplished by a single person with appropriate protective clothing. Accomplishing the same task with the ARMMS platform required substantial finesse by the operator in positioning and grabbing the stub-out. This technique was the only way the simulated bomb could be lifted by the manipulator without special tooling. Once the bomb was secured, it was placed in a container box. Average completion time among the test subjects was 7.0 minutes. The shortest task completion time was 2.33 minutes; the longest time was 14.7 minutes. The average number of attempts was 2.4 reflecting the difficulty in grabbing the stub-out tube. Two subjects utilized both arms to manipulate the simulated bomb. This resulted in the first and third longest task completion times.

W80 Vertical Uprighting

Uprighting a 770 lb. W80 shipping container was another task the test subjects faced. Without using the ARMMS platform, two very strong people, wearing appropriate protective clothing, were required to perform this task. The Titan 7F manipulators on ARMMS have a maximum rating at full extension of 250 lb. This rating, in conjunction with no convenient clamping points, made vertical uprighting of the 770 lb. container an extremely difficult task. Average task completion time was 31.2 minutes with significant time deviations between subjects. The shortest task completion time measured was 4.5 minutes; the longest time was 64.6 minutes. Three subjects attempted to utilized two arms. This resulted in the three longest completion times and the greatest number of attempts. Average time for single arm operation was 9.5 minutes versus two arms at 45.67 minutes. All successful vertical upright maneuvers were accomplished by using a single manipulator arm. The single arm approach involved using one swift brute force action. Any hesitation during the uprighting operation resulted in either the canister sagging to the ground, or the canister dropping to the ground from a lose of grip. Subjects using both arms would bind at a point when the container was partially uprighted.

W80 Laying Horizontal

For this task, the 770 lb. W80 shipping container was positioned on end and the operator was to lay the container horizontal on its side. Without equipment, two very strong people, equipped with protective clothing, are required to perform the task. When the ARMMS platform was utilized, the task centered around repositioning the container in preparation for laying it down. Once positioned, the act of setting down the container was straight forward. Average task completion time was 7.7 minutes with notable time variations between subjects. The shortest completion time was 15 seconds; the longest was 19.5 minutes. One subject utilized two arms. This resulted in the second longest completion time and highest number of attempts for success. All but two subjects were successful on their first attempt.

W80 Lifting

The final task facing the test subjects involved lifting the 770 lb. W80 shipping container completely off the ground. Without the use of any equipment, the task would require six people, equipped with appropriate protective clothing, to lift the container. To accomplish this task with the ARMMS platform, both manipulators are required in a dual coordinated manipulation effort. The average completion time was 6.2 minutes. The shortest completion time was 1.3 minutes; the longest time was 19.75

minutes. The average number of attempts to achieve success was two.

SUBJECTIVE TEST RESULTS

The following observations and experiences were noted by the test subjects:

* The Schilling Master Controller for wrist and jaw control was especially difficult to master and coordinate.

* Simultaneous dual arm manipulation was very difficult for the subjects. Each subject was frustrated by their inability to sense the individual forces being applied by each manipulator resulting in task attempt failures.

* Tasks become increasingly easier with experience.

ADDITIONAL EXPERIENCES

An F-4 fuselage scattered on the foothills of the Manzano mountains within Sandia's Robotic Vehicle Range (RVR) is used to emulate a plane crash site as shown in Figures 4 and 5. This crash mockup is being used to realistically explore the utility of the ARMMS at an accident site. The following lessons have been learned and observations have been noted in the course of over 50 hours of operational experience:

* The use of vehicle stabilization using outriggers is not necessary for heavy lifting.

* Special fabricated tools to facilitate operations were found to be extremely difficult to utilize. Preliminary tests involved the use of two tools constructed to aid in the lift of the W80 shipping container. The tools were made to fit into the container's fork tine openings. The act of obtaining, positioning, and using the tools proved to be far more difficult than direct manipulation of the container.

* Operations requiring extreme finesse are not practical with the commercial Titan 7F manipulator control configuration. Attempts at using the ARMMS to remove a nut and bolt from the W80 container locking ring were possible with the use of tools, but took a significant amount of time (tens of minutes) for an experienced operator to complete.

* Mobility in conjunction with manipulation is a powerful capability. In one exercise, one end of a chain was attached to the HMMWV. The arms were used to attach the other end of the tow chain to the fuselage of the plane wreckage. The HMMWV dragged the wreckage clear of the buried object.

* Equipment reliability appears to be an issue for the relatively harsh field environments experienced by the ARMMS. The Schilling Titan 7F master controller experienced failures associated with sand, causing master controller switch malfunctions as well as LCD blackouts. The blackouts were a result of ambient temperatures extremes and direct exposure to sunlight. In the course of testing, we have had two hydraulic hose failures within the arm; one o-ring failure and one return line rupture. Both arms have had their wrist position mode control capabilities fail.

* The Titan 7Fs have sufficient strength to penetrate and remove F-4 fuselage skin without any special tooling.

* The optimum separation distance between the manipulator bases on the ARMMS platform is 58 in. This was determined through a series of trial and errors. The Titan 7F manipulators have a reach of 78 inches yielding a reach to separation ratio of 1.34. It is interesting to note that anthropometric data [8] reveals that humans have a standing forward reach to shoulder width ratio of approximately 1.26.

Preliminary Observations using Teleoperation

The next phase of testing planned involves the evaluation of teleoperation effects on performance. The test setup will use three PIVS cameras and one forearm-mounted bore-hole camera for video and audio feedback also shown in Figure 3. The ARMMS teleoperator control station is shown in Figure 6 and consists of a Schilling master controller [6] and five PIVS video monitors [2]. Three of the seven subjects have completed the teleoperation testing at the writing of this paper. Notable observations thus far include:

* For successful task completion, the minimal setup requires two controllable cameras.

* Audio feedback was helpful but not crucial.

* Outside-in control is superior to inside-out control [7]. Outside-in teleoperation appears to increase task completion times by a factor of 3 over inside-out operations.

* Initial trials with a "Virtual Reality" stereo headset were disappointing. The headset required significant readjustments of both the headset and cameras between operators. Stereo vision could not be obtained for several operators. The benefit of the stereo vision was found to be insignificant in accomplishing tasks.

CONCLUSIONS

Initial evaluation of the ARMMS platform for use at an accident site has shown that the system is potentially a powerful tool. Capabilities are currently limited to salvage operations requiring only moderate finesse. A baseline to compare future enhancements has been established. Plans for future work include: (1) the performance characterization of teleoperation; (2) evaluating simultaneous manipulation and mobility; (3) evaluation of force reflective feedback [5]; (4) comparison/evaluation of pure robotic and telerobotic operations.

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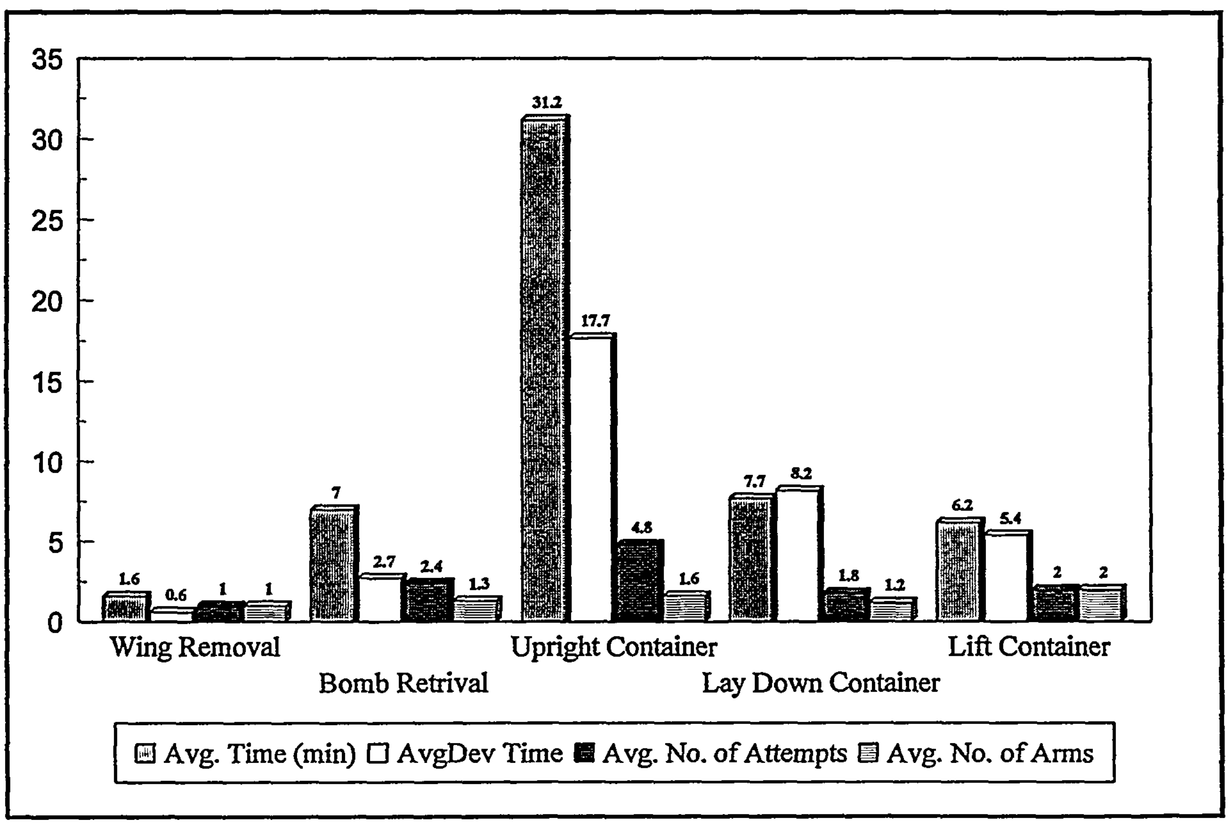

Figure1. Operator Task Performance Result Summary

Figure 2. Sandia National Labs Robotic Vehicle Range

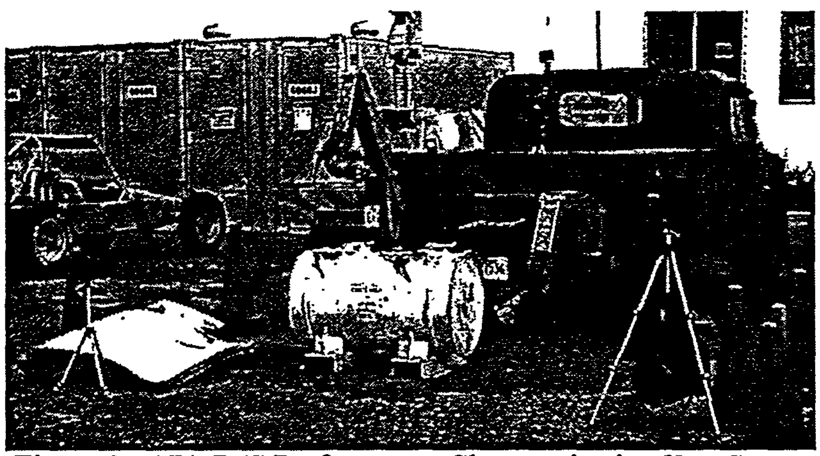

Figure 3. ARMMS Performance Characterization Test Setup

Figure 4. F-4 Crash Site Mockup

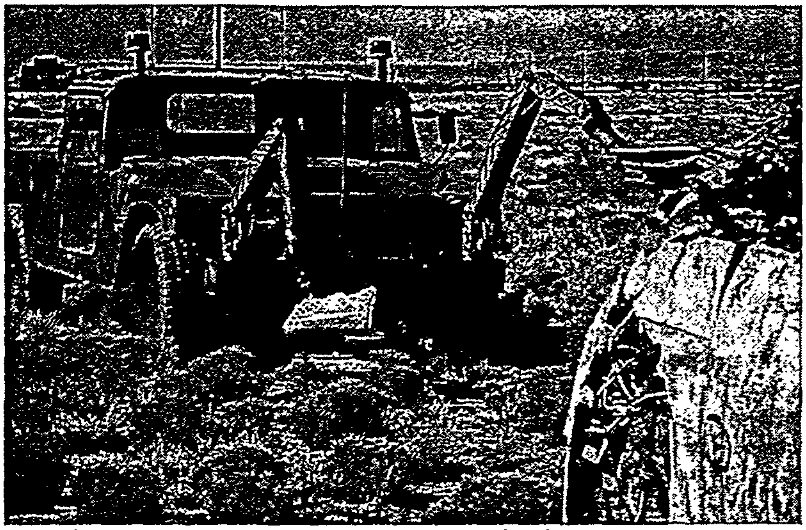
Figure 5. ARMMS at the F-4 Crash Site Mockup

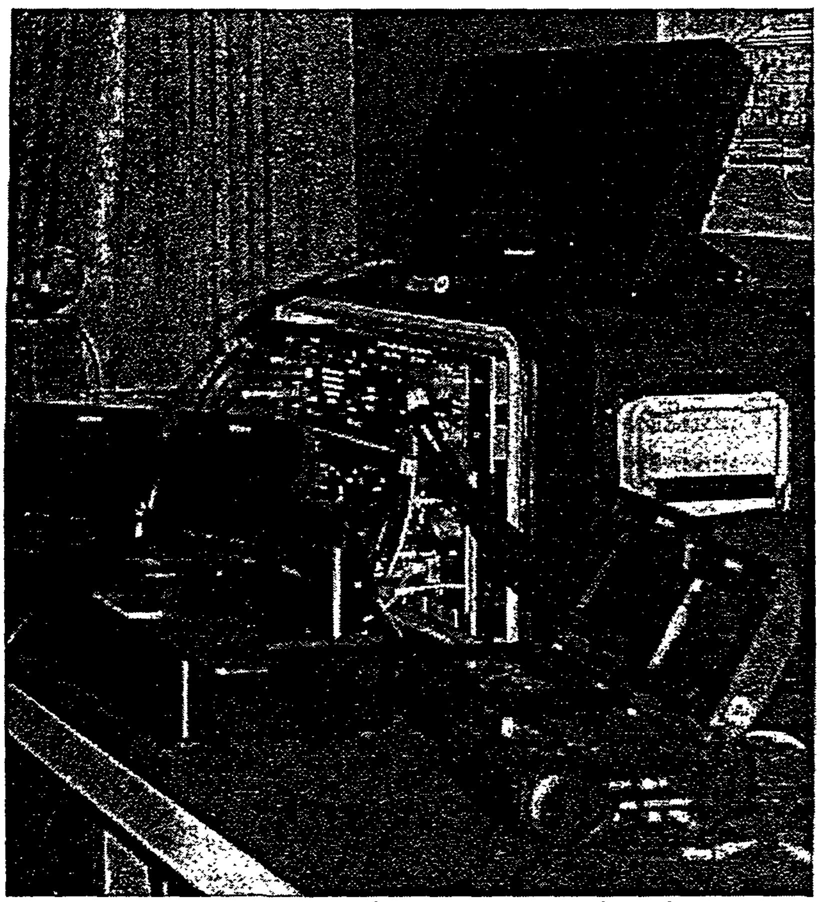
Figure 6. ARMMS Teleoperator Control Station