CONF-9503168--1

Next Generation Munition Handler Robotics

DEFINING THE NEXT GENERATION MUNITIONS HANDLER*

B. K. Cassiday
G. J. Koury
Robotics & Automation Center of Excellence
San Antonio Air Logistics Center
Kelly AFB, TX 78241

F. G. Pin
Robotics and Process Systems Division
Oak Ridge National Laboratory†
Post Office Box 2008
Oak Ridge, Tennessee 37831-6305

To appear in Proceedings of the
American Institute of Aeronautics and Astronautics (AIAA),
Computing and Aerospace 10th Conference,
San Antonio, Texas,
March 28-30, 1995

*Research sponsored by the U.S Air Force Air Combat Command, Munition Material Handling Equipment Focal Point, under Interagency Agreement 2146-H055-A1 between the U.S. Air Force San Antonio Air Logistic Center and the U.S. Department of Energy.

†Managed by Martin Marietta Energy Systems, Inc., under contract DE-AC05-84OR21400 with the U.S. Department of Energy.

DISCLAIMER

DEFINING THE NEXT GENERATION MUNITIONS HANDLER

B.K. Cassiday†, G.J. Koury† and F.G. Pin‡

†Robotics and Automation Center of Excellence
Technology and Industrial Support Directorate
Specialized Engineering Branch, Test and Evaluation Section
San Antonio Air Logistics Center, Kelly AFB, TX 78241
ti-race@sadis05.af.mil

‡Oak Ridge National Laboratory
Bethel Valley Road
Oak Ridge, TN 37831
pin@ornl.gov

Abstract

'Doing more with less' has always been the signature of the military man and is especially true of Air Force weapons handlers. However, as the military drawdown continues, the phrase takes on new meaning and becomes an unmistakable way of life for many. Unfortunately, all the resourcefulness in the world cannot overcome some obstacles, forcing a review of utility and mission effectiveness. How can we continue to reduce our resources and still meet our requirements? This paper documents the efforts under way to create a new tool for high fidelity, dexterous, heavy payload manipulation tasks. The ultimate goal of the Next Generation Munitions Handler Advanced Technology Demonstrator (ATD) is the identification and integration of the enabling technologies necessary to produce a system that reduces weapon loading times and operator workload while addressing mobility requirements.

Introduction

In recent years, the Air Force has commissioned several studies to examine the current and future roles of robotics and automation technologies in flightline operations. Few of these studies progressed beyond the point of paper analysis and even fewer resulted in hardware that received flightline testing. They also suffered from a basic lack of knowledge as to which robotic and automation technologies were applicable to the tasks. The net result being very narrow focus investigations into the usefulness of the technologies that did little to expand the knowledge base.

Why the difficulty? There were many contributing factors, not the least of which was the general focus on the development of fully automated systems to perform the tasks required during flightline operations. The flightline is a very dynamic and unstructured environment that does not lend itself well to 'hard' automation, due in part to insufficient machine intelligence. Development of machine intelligence to account for the environment is a very complex issue that is still several years away from practical implementation. Truly, evolution of systems incorporating the advantages of robotics and automation for flightline operations hinges on the ability to successfully overcome the shortcomings of a machine's cognizance.

Telerobotics must play a key role in this transition. Telerobotics centers on mixing the skills of human operators with the tireless precise positioning ability of a machine. The idea is to successfully determine the appropriate mixture of human/machine abilities to meet task requirements. Unfortunately, telerobotics is a concept, not an off-the-shelf technology. To correct this deficiency, the United States Air Force Materiel Command's Robotics and Automation Center of Excellence (RACE) embarked on an initiative to bring the benefits of telerobotics to the forefront. The Unified Telerobotic Architecture Project (UTAP) provides a standard framework of devices and interfaces which define a system capable of addressing a wide range of applications.

UTAP is in phase 3, the prototype development phase, designed to implement the Architecture/Interface specifications. The first implementation of the architecture is the Next

Generation Munitions Handler (NGMH) Advanced Technology Demonstrator (ATD). The NGMH is a logical extension of the UTAP due to the dynamic environment. The intent of the ATD is three-fold. First, provides a platform on which to evaluate the robotics and automation technologies on the flightline for applicability and robustness. Second, provides Headquarters Air Combat Command (HQ ACC) with valuable information on the utility of robotics as applied to munitions handling operations. Third, verifies the UTAP as a valid architecture.

The paper is broken up into three parts. First, a more detailed description of the UTAP is presented to familiarize the reader with the benefits of telerobotics and the usefulness of a standard architecture. Second, the discussion of the NGMH begins with a description of the munitions handling operations, followed third by a description of the current program plan and objectives.

Unified Telerobotic Architecture Project

In the Air Force, Air Logistic Centers (ALCs) provide the depot maintenance for a wide variety of components and systems. This capability is commonly called remanufacturing as the maintenance goes far beyond simple overhaul. In many cases, new parts must be manufactured and at times must be redesigned. The fact is, when an aircraft returns to an ALC for depot maintenance, the repair possibilities are endless. There is never a great degree of certainty as to which items will be repaired or replaced and the degree of effort that will be required to return the aircraft to a reliable level of flight worthiness. Thousands of industrial processes can be found across an ALC to provide the broadest base of support possible. However, because of small batch sizes, feature uncertainty, and varying workload, the use of classical industrial robotic solutions in an ALC environment is nearly eliminated.[1]

What the ALCs need are systems that bridge the gap between manual and complete automation. Shared control, of which telerobotics is a subset, provide the material to build the bridge. The term telerobotics defines a broad class of robotic systems where the actions of the man and machine are tightly coupled. The robotic device responds to human inputs and transfers the human motion into end effector motion. Unlike teleoperation, however, the robot maintains some local decision making authority. The human has superior cognitive and pattern recognition skills, while the robot is a tireless precise positioning system. The basic premise is to augment, not replace, the human operator by blending the individual skills of the two *systems*.

However, as mentioned, telerobotics is not an off-the-shelf technology. This fact and the potential benefits of telerobotics were the impetus for the Unified Telerobotic Architecture Program (UTAP). RACE has seized the opportunity to champion the creation of the cultural and technical infrastructure necessary for the implementation of telerobotics. The UTAP is to provide a standard set of devices and interfaces which define a system capable of addressing a wide range of applications. Many parallelisms can be drawn between UTAP and the personal computer industry. Standard architectures and interfaces are defined and adhered to allowing the installation of various vendors products without penalty.[5]

During UTAP phase 3, the prototyping phase, contracts are to be awarded to system integrators to implement the specifications. NGMH represents a prototype development for the UTAP and will be utilized as a verification of the architecture/interface specifications. Additional information on UTAP can be found in references [3,4,5].

Munitions Handling Operations

The majority of munitions handling operations involve the use of the MJ-1A/B Aerial Stores Lift Truck, known as the "jammer". The jammer is standard Air Force equipment used for loading munitions, fuel tanks, pylons, and special weapons weighing up to 3,000 lbs.[2] As seen in Figure 1, the jammer is a diesel powered, self-propelled vehicle that incorporates hydraulics to perform the heavy lifting required for munitions handling. Guidance of the vehicle is performed by the driver who is seated at the rear of the vehicle, far removed from the point of action.

A load crew is employed to perform the munition operations, which is generally comprised of three members, the driver and two additional members that perform the mating action as well as safety observance. The load crew is responsible for performing the detailed loading instructions in a quick, efficient, yet safe manner. The procedures for loading weapons on aircraft vary with the type of munition and also with the type of aircraft. The general procedures can be broken down into four basic steps; build up, transportation, installation and final hook up. While the details of each step are distinct for each weapon, the overall procedures do not change.

The first step, build-up, occurs in the munitions build up area, where the weapon is made

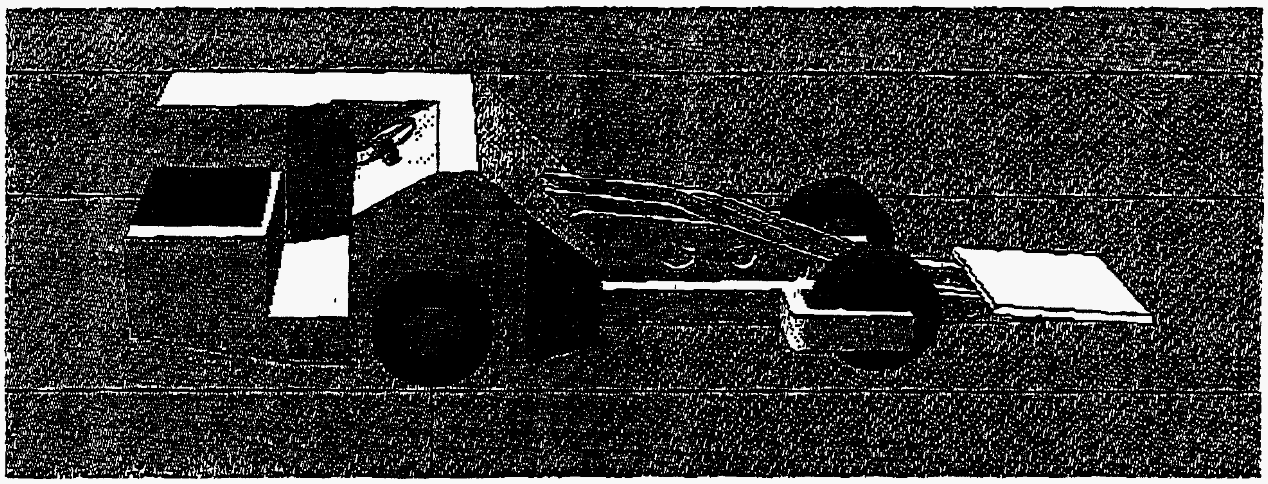

Figure 1: The MJ-1A/B Aerial Stores Lift Truck, The "Jammer"

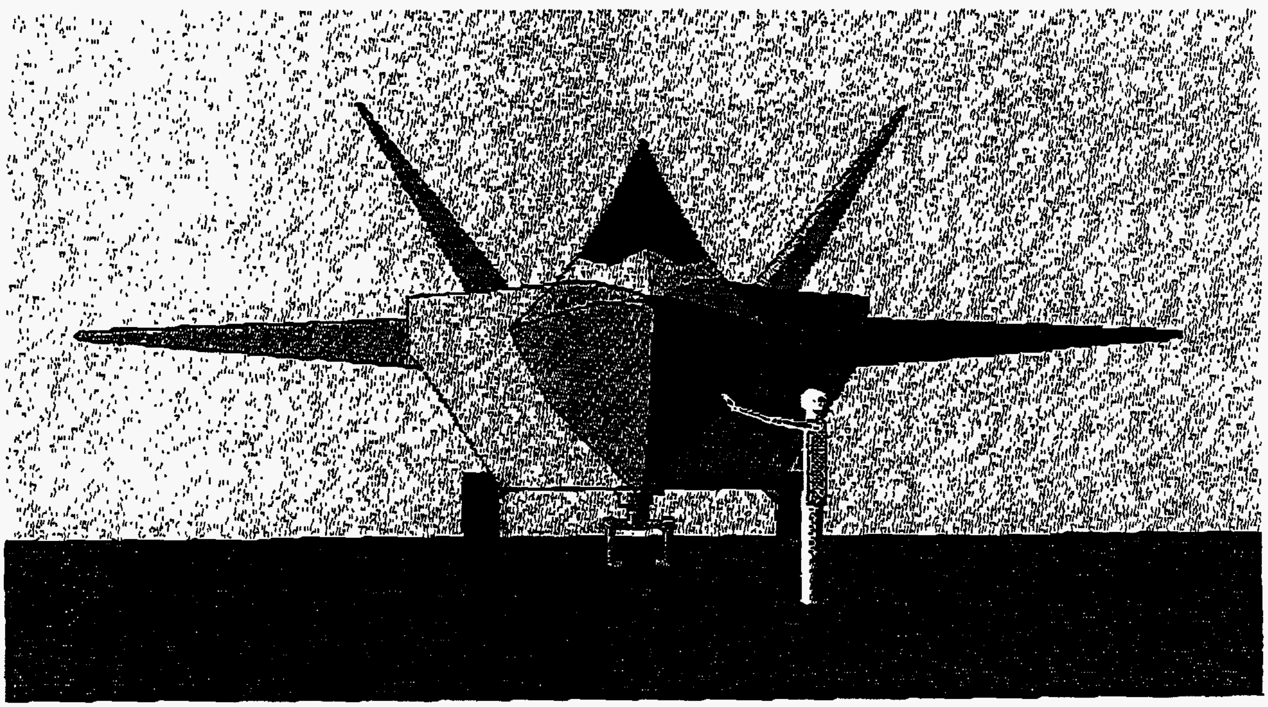

Figure 2: Air Force F-22

ready for loading. It is at this time that the weapon receives suspension lugs, fuse assemblies, fin assemblies, and any other wiring necessary for installation/delivery. Once complete, the weapon is transported to the loading area.

Transportation of the munition from the build up area to the loading area, usually an Integrated Combat Turnaround (ICT) area, is accomplished by securing the weapon to a munitions trailer, which is then towed to the ICT area. An ICT is the rapid retrieval and relaunch of combat aircraft. The loading of the weapons, barring serious aircraft mechanical or electrical failure, is the most time consuming part of the process and in a combat environment, timing is everything. ICTs are practiced in a confined area to simulate the hard aircraft shelters that are used in high threat combat situations. The jammer is used to transport the weapon from the trailer to the aircraft. During all operations with the jammer, communications between the driver and the other load crew members is constant. Due to the noise levels on the flightline, verbal communication between the driver and the other crew members is nearly impossible, so all communication is accomplished through hand signals. As the munition nears the loading station, fidelity of each movement is crucial. The crew member closest to the attach point utilizes separate fine motion controls for the final insertion of the weapon attach lugs into the bomb rack or missile rail. The munition is locked into place and the two loaders continue with final attachments while the jammer is safely driven away from the area.

The Air Force has utilized this effective loading procedure for several years. However, as with most systems, there is room for improvement. Several problems beleaguer this system. What at first appears to be a trivial task of mating two parts together in a desired configuration, becomes complex when tight part tolerances and limited visibility are factored in. The jammer system offers little in terms of user feedback and provides no ability to coordinate joint motions. All motion is accomplished through separate actuation of each individual joint.

The load crew is unable to sense the forces being exerted on the weapon and must adjust the weapon based on vision alone. In many cases, this is sufficient, but in others it is not. For instance, the loading of missiles onto missile rails involves aligning three missile lugs with rail attach points, inserting the lugs, then sliding the missile along the rail to lock into place. The jammer provides a vertical heavy lift capability, but the sliding motion takes place in the near horizontal plane. The tolerances between the missile and missile rail can be very tight, leaving very small allowances in misalignment. This typically results in the missile binding in the rail without any visual evidence.

Consider then, the situation encountered when loading an aircraft such as the Air Force F-22 (shown in figure 2). This aircraft employs the latest stealth characteristics, dictating the use of internal weapon bays. The primary weapon bay is in the belly of the aircraft, but the aircraft sits very low to the ground. The jammer cannot drive underneath the aircraft because of this low clearance making the weapon loading very difficult. The F-22 can only be loaded by closing one side of the weapon bay and then load from the opposite side of the aircraft. Even in this manner, the jammer can reach the far side weapon attach point by mere inches. The driver has no visual contact with the operation and adjustment of the jammer vehicle is difficult to achieve in close proximity to the aircraft.

The driver becomes a safety spotter for the members performing the mating operation, but his vantage point is restricted, and his usefulness is questionable. In this scenario, the driver represents little more than a platform input device - that which moves the vehicle in response to an external command. It is theoretically possible to eliminate the driver if the ability of the other crew members to interact with the vehicle is enhanced. Thus, the driver is free to perform other tasks that require his skills - thereby enhancing our personnel utilization.

Advanced Technology Demonstrator

In recent years, the Air Force has endeavored to improve the munitions handling operations through the use of modified procedures and improved equipment. The Munitions Materiel Handling Equipment (MMHE) Focal Point at Eglin AFB, FL has spearheaded this effort and one of their initiatives involved the study of robotics technologies as applied to munitions operations. The MMHE Focal Point entered into an engineering study with the University of Utah to evaluate the robotics technologies and their applicability. The University of Utah report correctly identified munitions handling equipment (i.e. the jammer) as an area that could potentially benefit from incorporation of advances in robotics technology.[6] The goal of a next generation munitions handler is to reduce weapon loading times and operator workload while decreasing mobility requirements. However, achieving these goals is a non-trivial task. The fundamental technologies necessary for implementation of the next generation munitions handler exist, in one form or another. However, the most efficient method remains a mystery. Thus, the

Air Force has entered into a joint development effort with the national laboratories to produce an Advanced Technology Demonstrator (ATD) munitions handling platform.

The point should be made as to the difference between a prototype and an ATD. Prototype implies the basic design is well defined and only requires verification. However, in the case of the NGMH, the basic design is not well defined and the utility of the various robotic technologies as applied to this task is not understood. An ATD affords the opportunity to evaluate these technologies for applicability. The intent is to demonstrate the usefulness of a technology instead of the usefulness of a particular system.

The MMHE Focal Point, at the direction of HQ ACC, maintains overall program management responsibility and provides funding and user technical input throughout the various phases of the program. The Robotics and Automation Center of Excellence (RACE) maintains overall control of engineering and technical requirements as well as providing robot simulation support to the labs involved in the effort. In addition, RACE completed the requirements definition phase of the program. Oak Ridge National Laboratory (ORNL) acts as the prime contractor on the development of the ATD manipulator, human interface, control system, and mobility platform. As the prime, ORNL is responsible for the design, development, manufacture, and integration of these components. These responsibilities include aligning with the current RACE UTAP partners to identify and implement the human interface and control system.

The basic mechanical design of the manipulator is fairly well understood. The critical system design issue is how the operator will interface with and operate a telerobotic munitions handler. Different possibilities may include "come-along" technology, gravity compensation with operator control handles, and semi-automated terminal convergence. Other possibilities include an operator joystick and Remote Center of Compliance technology for terminal mating. The ATD development is concentrating on the design of a manipulator encompassing the enabling technologies necessary to determine the optimal mechanical and human interface configurations. The goal of the ATD is to provide a solid mechanical design with a telerobotic control system that allows rapid reconfiguration to evaluate different control strategies for the human interface. The sensor suite chosen is to provide the maximum flexibility possible.

Unique sensor requirements are generated by the development of a dexterous, heavy lift manipulator. Commercial force sensors have the ranges and fidelity to meet the requirements for lift and manipulation, but cannot withstand the accidental impacts expected. The loading of missiles onto the aircraft require "square peg into square hole" in doublet and triplets. The holes are non-chamfered, rendering the classic insertion process, utilizing remote center of compliance devices, ineffective.

The RACE requirements analysis determined the breadth and width of the program scope. The ATD development is a multi-phase effort. Phase I is the development of a system design, including both preliminary and critical design reviews, and leverages off the technologies developed in the Navy Omnidirectional Vehicle program, ORNL Ammunition Logistics Program, and the University of Utah investigation results to the maximum extent feasible. Phase II, fabrication, includes the construction integration and evaluation of the manipulator, controller, and terminal mating systems. Phase III is the acquisition or fabrication and evaluation of the mobility platform. This phase can proceed concurrent with phase II. Phase IV, integration, merges the manipulator, mobility platform, control and terminal mating systems into a fully operational ATD. Phase V, trial and analysis, consists of benign environment field testing of the system by RACE. The funding of the ATD is incremental by phases.

Conclusion

Presently, the NGMH ATD program is nearing completion of the design phase. The program has grown into a collaborative effort between the Air Force, Navy, and Marines and efforts are underway to identify the broad base applicability of the technology as well as the dual use potential. The end result of this ATD effort is a comprehensive understanding of the benefits of telerobotic munitions handling and the specifications necessary to produce the next generation munitions handler.

Bibliography

[1] *Generic Telerobotic Architecture for C-5 Industrial Processes*, JPL Final Report, August 1993.

[2] Ground Support Equipment for Aerial Stores Handling and Aircraft Maintenance, *Engineering Specifications, Issue No. XVI*, Standard Manufacturing Company, Inc., Dallas, TX., 1990.

[3] M. B. Leahy, Jr. and B. K. Cassiday, RACE pulls for Shared Control, *Proceedings of SPIE Conference on Cooperative Intelligent Robotics in Space III*, Boston, MA, Nov 16-18, 1992.

[4] M. B. Leahy, Jr., and S. B. Petroski, Telerobotics for Depot Applications, *Proceedings of NAECON 93*, Dayton, OH., May 1993.

[5] M. B. Leahy, Jr., and S. B. Petroski, Telerobotics for Depot Modernization, *Proceedings of the AIAA Conference on Intelligent Robots in Field, Factory, Service, and Space (CIRFFS)*, Houston, TX., March 20-24, 1994.

[6] *Robotics Application to Munitions Operations*, University of Utah Center for Engineering Design Final Report, February 1994.