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AN INTELLIGENT INSPECTION AND SURVEY ROBOT

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CONTRACT INFORMATION

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Introduction

ARIES (Autonomous Robotic Inspection Experimental System) is a semi-autonomous robotic system intended for use in the automatic inspection of stored containers of low level nuclear waste.

The project is being performed by a team under the SCUREF (South Carolina University Research and Education Foundation) comprised of the University of South Carolina, and Clemson University, and their industrial partner Cybermotion Inc., with funding from METC, Morgantown, WV.

The ARIES program is unusual in the level of cooperation between the universities and Cybermotion. By maintaining daily communications via telephone and E-Mail, participating in frequent meetings with each other and the end users, and by developing an open flow of (sometimes sensitive) technical information, the team has been able to build on a very broad of base intellectual strengths and existing technology without wasteful duplication.

This base includes all of the navigation and control software and hardware developed by Cybermotion over nearly a decade and the deep technology resources of the university partners. It is anticipated that the result will be a technically advanced system that is much closer to a deployable configuration than is typical for this stage of research. In this decade of shrinking budgets, such relationships can provide a crucial advantage for all participants.

The Problem

The Cold War production of nuclear weapons generated an enormous quantity of low level nuclear waste within the DOE community. This waste contains inert items such as gloves, booties, and a limitless variety of tools, rags, and other items mixed with both radioactive and chemically hazardous compounds.

Until all this waste can be separated and disposed of, it must be stored and monitored to assure that it does not present a health hazard to the environment. The problem is compounded by the fact that higher level waste must be given priority in the disposal process.

At present, the waste is stored in drums of a variety of sizes from 55 gallons up to 110 gallons, and in large box like containers. These containers are stored in turn in unheated shelters ranging from Quonset hut like tension structures to traditional warehouses and even open sided shelters.

Since many of these drums contain corrosive liquids, they must be inspected regularly to prevent leakage. When a drum is found to be in danger of leaking, it is typically "over packed" into a larger container.

Drums are stacked as much as four high in aisles that are 36 inches wide. To aid in problem detection, the drums are stored with their seams (the weakest region) toward the aisle.

Objective

The objective of the ARIES project is to develop a robot, equipped with a machine vision system, that is capable of moving autonomously from its charger area to any storage aisle; maneuver down the aisles; identify, photograph, and evaluate individual drums; and return to its charger.

It is the further objective that the system be capable of bringing a manipulator or appropriate instrument to a suspect drum for the purposes of further remote evaluation.

As previously stated, it is the goal of the participants that this system should be produced as close as possible to a field ready configuration.

Visits to the user site at Frenauld provided a valuable insight to the end user's priorities. Foremost among the desires expressed was throughput. As a result of the emphasis on throughput, the preliminary design of the camera lift was modified to include more cameras and thus require less time for positioning them.

Preexisting Technology

During phase I of the ARIES project, Cybermotion worked as an unfunded partner to assist USC in demonstrating the capabilities of the existing technology relative to this application.

This work was done on University of South Carolina robotic testbed platform called MARVIN. MARVIN was based on Cybermotion's commercial Navmaster (TM) vehicle. The Navmaster is an autonomous vehicle that navigates by a suite of techniques using primarily its sonar. Cybermotion's contribution during phase I was to assist USC in the integration of additional systems onto MARVIN in order to demonstrate the feasibility of navigating in drum aisles using sonar imaging techniques.

During phase I, USC and Clemson also demonstrated the feasibility of other components such as the vision system. MARVIN was demonstrated as it left its charger, navigated down a drum aisle, and returned to its charger.

The programming, docking and autocharging capability demonstrated were some of the many legacies that the system inherited from the outset due to its commercial roots.

Required Improvements

Unfortunately, the Navmaster vehicle was not designed to navigate in spaces narrower than 48 inches. The K2A Mobile Platform, on which the Navmaster is based, has a 32.75 inch footprint, making it too wide for safe navigation in a 36 inch aisle.

Additionally, the sonar system of the Navmaster will not work well in aisles narrower than 40 inches due to the minimum range window of its standard side looking sonar. During phase I, 48 inch aisles were used to avoid these limitations.

Furthermore, the sonar navigation technique developed, which was based on triangulation using the law of cosines, was implemented on an onboard VME computer, and not in the K2A native software. For this reason it suffered from speed limitations.

It also became apparent during phase I that at least one additional set of

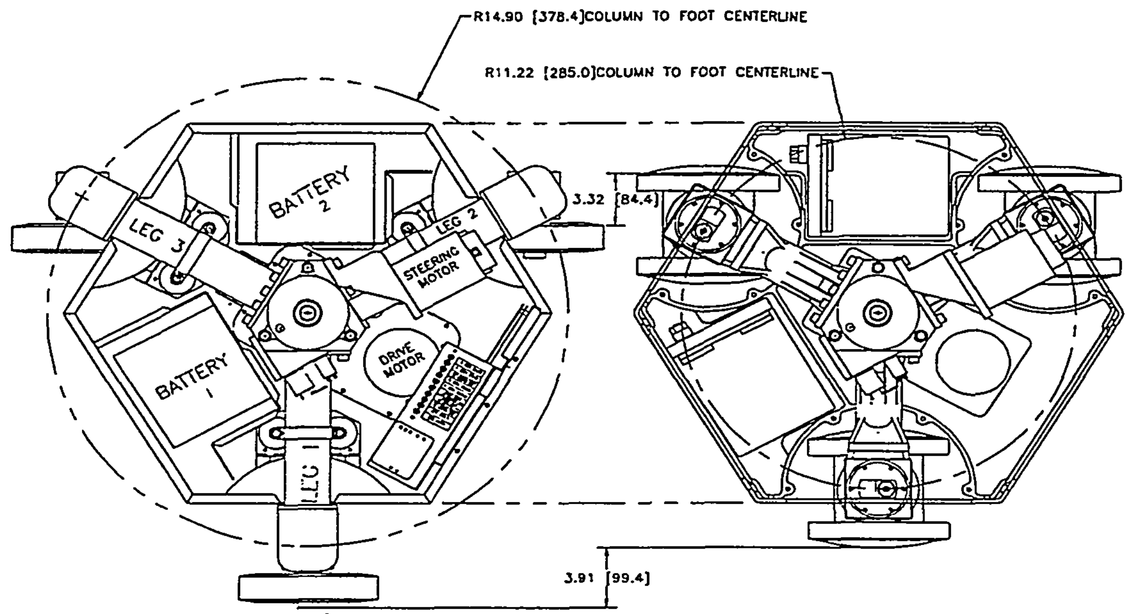

Figure 1 - K2A Footprint Figure 2 - K3A Footprint

sonar sensors, looking to the front and sides would be required for such confined spaces. Using such "sonar cat whiskers", the vehicle could image drums before it was lateral to them. This addition of sensors was already being developed for the Navmaster and could thus be included with little cost to the program.

Phase 2 Hardware

In order for phase 2 to meet these objectives, Cybermotion would have to overcome the limitations of its vehicle in narrow aisles. Fortunately, a new narrow profile base, designated the K3A had already been designed. Armed with a sale for one of these new vehicles, Cybermotion proceeded to pay the tooling costs required to manufacture the first five K3A mobile platforms. This platform has been assembled and was tested in early October.

The modified turret is in the final design process at this writing, and the camera lift is about to transition from the conceptual to the hardware design phase. For this reason, only the K3A will be discussed in detail.

The K3A Mobile Platform

The geometry of the K3A is similar to that of the K2A, except that each of the three foot assemblies has two wheels. With a wheel on either side of the foot, the stability limitation encountered in the K2A was eliminated, and the legs were made shorter. With its smaller footprint, lower center of gravity, and dual-wheel design, the K3A provides narrower clearance (27.125 inches / 68.9 cm) and considerably improved stability.

At first observation, this would appear to be a simple and obvious improvement, however this appearance is deceptive. The use of a common drive axle between wheels on a foot would obviously not allow turning. A differential between the wheels, the use of one idler, or a ratchet drive on the wheels, while allowing turning, would greatly reduce odometry accuracy and control.

It is therefore essential that the two wheels of each foot rotate in lock when driving but counter rotate during steering, and that all six wheels remain locked in drive.

In the K3A design, this is accomplished without differentials and all six wheels remain mechanically locked to the drive motor. This synchronization is essential to prevent traction loss on uneven surfaces, when one wheel of a pair may leave the floor. Additionally, both the steering and driving forces around a foot assembly are balanced, improving odometry.

The mechanism of the K3A uses bevel gears and concentric shafts identical to the K2A to deliver drive and steer forces to each foot via cast "leg tubes".

Within each foot, a slip free mechanical "Adder" adds positive drive movement to one wheel and an equal negative movement to the other wheel of the pair in proportion to steering movement. The equation for motion of the two wheels is therefore:

$$\omega_{W1} = R(\omega_D - \omega_S)$$

$$\omega_{W2} = R(\omega_D + \omega_S)$$

Where:

ω_{W1} = Angular velocity of Wheel 1

ω_{W2} = Angular velocity of Wheel 2

The K3A has several advantages over the K2A mobile platform. Among these advantages are:

Smaller Footprint
Improved Stability
Improved Odometry
Improved Traction
Reduced Scuffing

The smaller footprint and improved stability are derived from the fact that since there is a wheel on each side of the foot assembly, the leg may be made shorter without jeopardizing stability. The improvement in clearance for the K3A is shown in Fig. 1 and Fig. 2. This improvement means that the K3A may travel easily through areas as narrow as 36 inches, and that it may travel faster in areas that would challenge the K2A.

Since the driving forces of the wheels are equal, the odometry of the K3A benefits from the fact that forces around a foot are balanced in both acceleration and deceleration. Furthermore, the K3A is truly a six wheel drive vehicle, giving it unmatched traction. In tension structures it is not uncommon to encounter ice, and the presence of dikes requires good climbing ability.

A final, and less obvious advantage is gained with the dual wheel geometry, and that is related to the fact that each tire is only about 60% as wide as a K2A tire. Since the weight of the vehicle is distributed on six tires, there is less pressure per square inch on each tire even at this reduced width. As a tire turns around the foot assembly, the gear ratio discussed earlier is set to cause the center of the tire to turn at the proper rate to traverse the steering circle. The outside and inside edges of the tire, however are slightly different distances from the center of turning, and thus distortion of the tire and some scuffing occur.

Both the K2A and K3A use a flat tire surface with about a 70 durometer material. On the K2A, it has been found that vehicles operating continuously for several years will begin to form a crowned surface on the tire due to excess wear on the edges. The reduction of the width of the K3A tires, combined with the lower pressure per square inch, significantly reduces this undesirable effect.

The Turret

The turret of the Narrow Aisle vehicle is required to turn in a 36 inch wide aisle. The turret of the standard Cybermotion Navmaster is oblong and will barely turn in a 36 inch circle. For this reason, a shortened turret is being fabricated for the Narrow Aisle vehicle.

The changes that this shorter turret will enforce on the underlying code will be compensated for by a simple change of default values already existing as programmable variables in the K2A software (the software having been written with such contingencies in mind). In all other aspects the K3A uses existing and tested K2A software. The turret of the ARIES robot will contain all of the standard Navmaster hardware and a VME based computer system which will be used primarily for vision processing.

The Camera Lift

The camera lift will position four camera packages to nominally observe the center of each drum on a stack. It will be possible to move the relative position vertically, with all cameras moving to the same position on their respective drums. Because of the requirement to turn in the aisle, combined with the need to view the lowest drum at a point lower than the top of the vehicle, the lowest camera assemble will deploy from the rear of the vehicle.

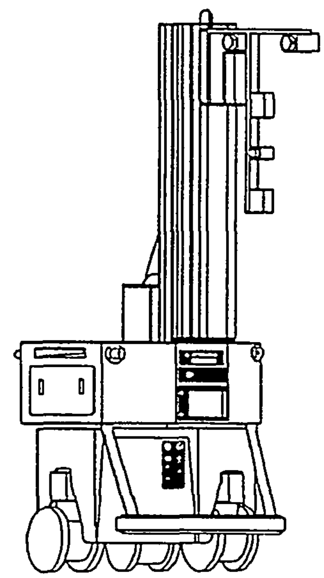

Figure 3 - K3A w/ Camera Lift

The relative motion of the cameras will be mechanically synchronized so that only one motor is required to deploy, retract, and position the main boom. The lower drum camera positioner will be deployed by a second motor.

It is desired, though not required, that the lift be collapsible to a total height of less than 7 feet. This capability will permit the vehicle to move around the ends of the tension structure where the curved roof limits clearance near the wall. It will also improve stability during transition across dikes and ramps.

Concurrent Projects

The Narrow Aisle vehicle will benefit from several other programs currently underway at Cybermotion. These programs include the MACS Floor Characterization Robot being integrated by Savannah River Laboratory, and the MDARS Interior Security Robot Program.

The MACS robot includes a Navmaster(TM) - K2A platform integrated with a LIDAR (Light Radar) system from TRC in Danbury CN. The LIDAR system allows MACS to navigate from reflectors located about the facility, freeing it from the restrictions imposed by sonar navigation.

The MACS firmware, which was delivered earlier in 1994, has been included in all K2A and K3A platforms and seamlessly integrates this new navigation technique with the existing sonar and beacon capabilities. MACS is a component of the DOE D&D Robotics Program and is scheduled for demonstrations at Oak Ridge in Spring 1995.

The U.S. Army MDARS program is directed toward fielding a mobile robot to perform security and inventory functions in DOD warehouse facilities. MDARS requires several enhancements to the Navmaster vehicle as well. This work, which will continue through 1995, will include several improvements beneficial to the Narrow Aisle Vehicle.

Among these improvements are the integration of ethernet radios onto the vehicle, and the improvement of its sonar system to facilitate the addition of more transducers for better coverage in tight areas.

Conclusions

The Inspection Robot system described is a direct reflection of the new and pressing emphasis within DOE and DOD toward dual use of commercial and government technology.

The unusually close teaming between SCUREF and Cybermotion has allowed the program to leapfrog years of development by building upon existing commercial technology. At least as important to Cybermotion is the fact that the progress made under this program will benefit its commercial customers as well.

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