DEPLOYMENT OF ROBOTIC DEVICES FOR HIGHWAY MAINTENANCE AND CONSTRUCTION

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ABSTRACT

The California Department of Transportation and the University of California, Davis have jointly established the Advanced Highway Maintenance and Construction Technology (AHMCT) Center to explore the application of automation and robotics in transportation infrastructure construction and maintenance. This paper presents a brief overview of current research being conducted by the AHMCT Center including descriptions and photographs of automated and/or robotic systems under development. Special emphasis will identify unique requirements imposed by the highway, the benefits of each system relative to conventional maintenance and construction operations, general system descriptions and the current status of six projects nearing final deployment in California.

INTRODUCTION

Of considerable concern to maintenance and construction engineers at the California Department of Transportation (Caltrans), is the ability to safely and efficiently perform tasks with minimal impact to the traveling public. This is a staggering problem as the increasing age of the facility dictates ever expanding levels of work. In California, this is exacerbated by recent reductions in the maintenance and construction work force coupled with rapid increases in traffic volumes and resulting congestion which continue to reduce the "window of opportunity" available to perform necessary operations. Even more challenging situations begin to surface as transportation engineers contemplate the implications of Intelligent Transportation Systems.

In response to these pressing concerns, Caltrans and the University of California, Davis (UCD) established the Advanced Highway Maintenance & Construction Technology (AHMCT) Center in 1989 to investigate the application of automation and robotics to highway maintenance and construction. The Center is jointly managed by Caltrans and UCD and base funding is provided by Caltrans, the Federal Highway Administration, UCD, and other public and private sources.

This paper presents a brief overview of current research being conducted by the AHMCT Center including automated and/or robotic systems currently being field tested or deployed in California. Special emphasis will identify unique requirements imposed by the highway, the benefits of each system relative to conventional maintenance and construction operations, general system descriptions and the current status of six projects nearing final deployment in California.

AHMCT CENTER EFFORTS

Transportation system maintenance and construction is essential to ensure the safe, efficient, and effective delivery of people, goods, services, and information. However, current transportation maintenance and construction activities depend comparably little upon high technology equipment or procedures relative to other industries. Many current activities are labor intensive and can expose workers and travelers to the risk of injury. The application of technological innovation and systems improvement can make highways safer for their stewards and travelers, speed task completion, and reduce associated costs.

Correspondingly, the goals of the AHMCT Center are to greatly improve the level of safety that now exists for maintenance and construction personnel, substantially increase the speed and efficiency of maintenance and construction operations, reduce the effect that maintenance and construction operations have on the traveling public, increase the reliability of the highway infrastructure, and mitigate environmental impacts of highway maintenance and construction activities.[1]

PROJECT DEVELOPMENT

Research and development projects undertaken at the AHMCT Center are selected for their potential to resolve significant challenges that affect safety, efficiency, and cost savings. A project begins with user surveys of perceived need and recommendations for service, process, method, or equipment improvement and innovation. Selected projects must meet the test of broad application and demonstrate strong potential for successful field implementation as well as product commercialization.

The pre-prototype research phase involves thorough feasibility studies, cost/benefit analyses, and literature searches. Prototype development includes periodic design reviews and intensive evaluation by transportation maintenance and construction personnel. Observations from transportation workers are incorporated into prototype improvements until a field-operational engineering prototype is developed. This prototype is tested extensively in all environments and by actual users. Comments and recommendations contribute to continued improvements until a reliable prototype is developed. This "field prototype" is then deployed to various regions for long-term evaluations relative to operation, reliability, and its ability to satisfy the original project goals. Finally, product manufacturers advance the product from its prototype stage to commercial marketability so that it can become a useful and cost-effective innovation of benefit to all public and private transportation organizations.[2,3]

PRODUCT DEPLOYMENT

The following descriptions (AHMCT Center brochure, 1994) represent a small subset of products that the AHMCT Center is investigating and include prototypes in either the field testing or field deployment stage of development. These projects were selected to emphasize the wide diversity of maintenance and construction tasks addressed by the AHMCT Center as well as the associated multi-disciplinary teams necessary to provide successful technology solutions.

Longitudinal Crack Sealing Machine

Caltrans is responsible for maintaining over 15,000 highway miles of roadway. Repairing pavement cracks helps retain the structural integrity of the roadway and extends the time between major rehabilitation. Longitudinal crack sealing, an important subset of generalized crack sealing, can be a dangerous and tedious operation. The Longitudinal Crack Sealing Machine (LCSM) will enhance worker and traveler safety, lower highway maintenance costs, and improve efficiency in crack sealing operations.

The LCSM employs a self-contained modular design that simply mounts to any maintenance vehicle, thereby eliminating the need for dedicated vehicles for this activity. The driver of the vehicle is able to view the sealant applicator at work and simply follows the longitudinal

FIGURE 1 Longitudinal crack sealing machine.

crack. The applicator has been designed in two versions, one for crack sealing and one for crack filling. The crack sealing applicator maintains a reservoir of pressurized sealant thus forcing the material both into the cracks and into a flush overband configuration. Both applicators provide an adequate amount of sealant material regardless of crack width and depth. Figure 1 shows the sealant applicator in use on a standard Caltrans truck.

Due to the significant increase in sealant speed, the LCSM has been limited by the commercially available sealant melters and the manner in which personnel re-stock sealant material to the melter. Accordingly, a new material handling approach has been developed which has included minimal additions to a standard sealant melter and has allowed the operation to proceed at an accelerated rate. Personnel requirements include a driver and one operator seated on the bed of the vehicle to provide blocks of sealant to the melter's material handling system.

A field prototype of the LCSM has been deployed with Caltrans maintenance personnel which has allowed debugging and minor modifications to best meet the needs of on-road operations.

Robotic System for Roadway Stenciling

Pavement markings are a necessary element of traffic delineation and control, but present significant safety problems during required installation and maintenance.

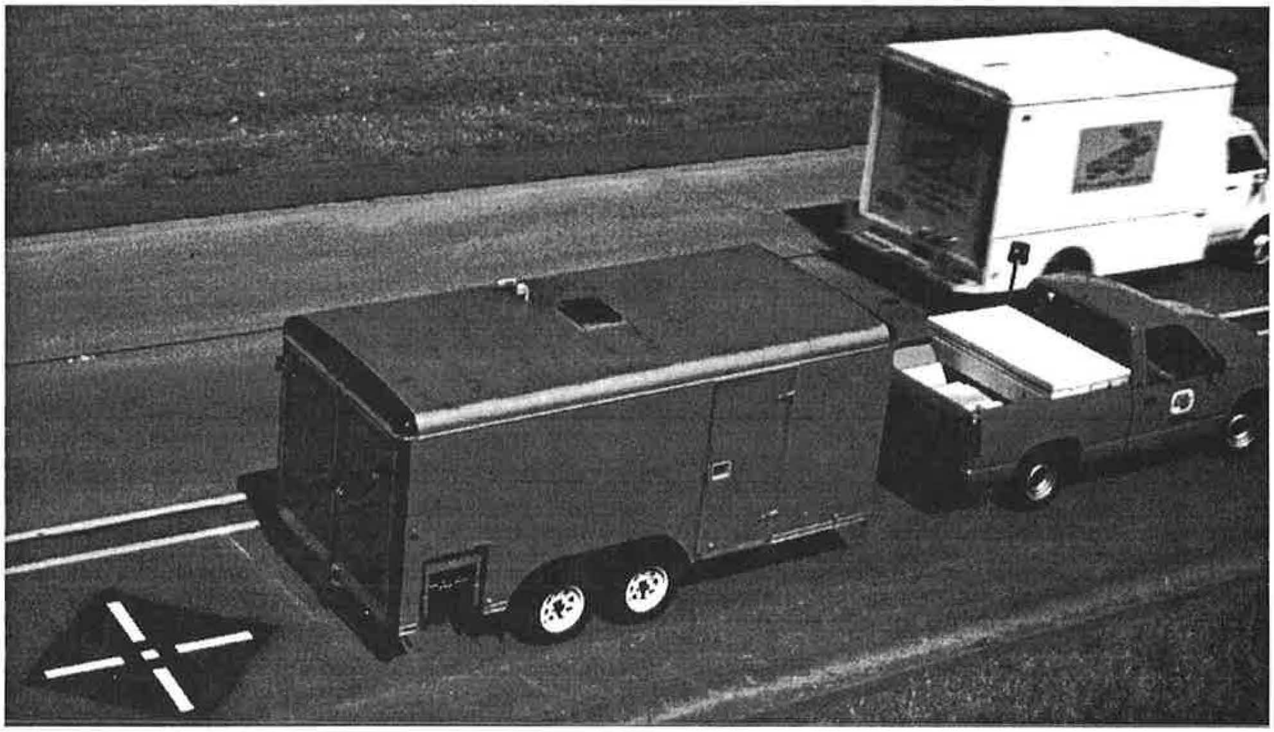

FIGURE 2 Robotic system for roadway stenciling.

Current methods to apply pavement symbols and signage require the manual placement of a stencil on the pavement, followed by the manual application of paint or the "torch-down" of a thermoplastic type material. Both procedures are very slow and labor-intensive operations that expose maintenance employees to traffic and possible injury.

An automated, robotic processing system has been developed that improves efficiency and worker safety using a spray gun that is guided by a robot manipulator. A single operator is now capable of planning the operation on-site, positioning the vehicle for proper alignment, and completing the stenciling operation from within the cab of the maintenance vehicle.

Developed in response to an employee fatality, the initial robotic sign stenciling machine focused on improving the safety of the application of photogrammetric "premarks" or targets. Premarks are currently painted by manual means on the road surface and are used in conjunction with aerial photography to calibrate vertical positions. A four-person survey crew may require five to seven days to paint target marks on 1.6 km (1 mi) of highway. The robotic stenciling system developed completes the same operation in less than one day.

The system consists of a self-contained gantry type robotic system housed inside a closed trailer. This is shown in figure 2. The gantry robot (x-y plotter) is designed to pass two rows of painting nozzles (one white, one black) over the asphalt surface to complete the mark. Motors and pneumatic cylinders are used to lift the stenciling apparatus from the truck to the ground, thereby eliminating the need for workers to be exposed to vehicular traffic on the roadway. All operation of the robot is completed from the cab of the vehicle, virtually eliminating traffic exposure.

The Robotic System for Roadway Stenciling has been successfully field tested throughout California and is currently being deployed on a state-wide basis.

Smart Herbicide Application

Vegetation control on the transportation system right-of-way is a necessary component of Caltrans' highway maintenance program. Uncontrolled weed growth impedes driver visibility, fuels grass and forest fires, and contributes to pavement degradation.

Caltrans employs an integrated system of vegetation control which includes mechanical methods, use of low-growing, drought tolerant and fire-resistant plants, and herbicides. Caltrans, committed to reducing the amount of herbicides used in vegetation control, intends to reduce its use of herbicides by 80% by the year 2012. The Smart Herbicide Applicator will help to achieve this commitment, reduce highway maintenance costs, and

FIGURE 3 Smart herbicide applicator.

improve working conditions for landscaping crews by intelligently applying herbicide accurately with minimal over-spray. This is achieved through the automated and targeted application of herbicide to plant material only.

The Smart Herbicide Applicator employs a vision sensing system to detect green plants and has a targeted field of view of up to 2.4 m (8 ft) perpendicular to the traveling vehicle. Image processing is used to identify the exact location of detected plants while the vehicle is in motion and leaf sizes as small as 0.125 m^2 (1.9 x 10^4 in^2) can be detected. A speed-compensated control system utilizes data from the image processor and a radar-based speed detector to activate the spray nozzles. The ground speed detector is necessary to determine the trajectory of the herbicide and the nozzle action required for targeting. The combination of this data enables the controller to specify the exact moment to actuate the appropriate applicator nozzle so that only the detected plant is targeted. Rapid-response spray nozzles on a boomless vertical nozzle bank precisely direct the application of herbicides to plant tissue and reduce over-spray. The Smart Herbicide Applicator is shown in Figure 3.

The field-testable unit, integrated on a standard Caltrans maintenance vehicle, is now undergoing testing and evaluation under regular maintenance conditions in Northern California. Regional vegetation control crews using the system are providing feedback for optimization of the system - a step critical to developing equipment acceptable and usable by the maintenance work force. A subsequent development project will modify the Smart Herbicide Application System for integration with the more modern chemical-injection equipment existing within the Caltrans vegetation control program.

Telerobotic Litter Bag/Debris Collection Vehicle

Litter bag and debris removal operations vary in procedure, but have in common low efficiency, moderate costs, and high risk of injury. Typical operations require a single worker to drive along the roadside, periodically stopping to throw bags or debris from the roadside into the cargo body of the truck. The Telerobotic Litter Bag/Debris Collection Vehicle, developed by the AHMCT Center, has demonstrated the potential to greatly improve safety and efficiency over manual retrieval. The objectives of this vehicle are to reduce the number of personnel required for the operation, keep the worker off of the unsafe roadside and away from the health hazards implicit in manually lifting litter bags and debris while still allowing efficient performance.

The Telerobotic Litter Bag/Debris Collection Vehicle has the multi-terrain ability to pick up litter bags and large debris from either side of the standard, but slightly modified, compacting garbage truck at levels within 1.2 m (4 ft) above or below grade. The hydraulic clamshell-type manipulator mounted between the cab and the compactor of a truck can grip objects such as single or multiple litter bags, tires, mufflers, and lumber. The maximum payload of the bucket is approximately 45.4 kg (100 lbs). Recent field testing has demonstrated that the machine has the ability to pick up several large tires or up to 8 litter bags at one time.

This design has the enormous benefit of automatically performing the repetitive task of bringing the load to the compactor, dumping the load, and returning the manipulator to a ready position, while allowing the operator to maintain his position within the cab of the vehicle. Macro and micro control of the manipulator is provided to the operator in a very user-friendly format. Macro control allows the complete pickup cycle to occur with the push of just two buttons and with a cycle time of under 60 seconds. More flexible or micro control is provided when debris or litter bags are placed in inconvenient locations as on the backside of guardrail or near roadway signs.

This machine has been successfully field tested throughout the state and is scheduled for statewide deployment in 1996.

FIGURE 4 Telerobotic litter bag/debris collection vehicle.

Teleoperated Front-End Loader

The use of heavy equipment, such as crawler tractors, dozers, and loaders, is crucial to highway maintenance and often used in hazardous operations. They are used to repair highway damage after an avalanche, clear landslides, clean up hazardous materials, and clear snow on winter storm-closed highways. In such operations - where soil and snow banks are unstable, road boundaries not recognizable, or toxicity of potentially hazardous spills unknown - operators work in a high-risk environment. Casualties and injuries occur every year across the nation, despite preventive efforts. Teleoperated machines have the potential to perform many of the required jobs and reduce worker exposure to dangerous conditions.

The Teleoperated Front-End Loader consists of a remote controlled system applied to a Case Model 621 front-end loader. The teleoperated concept allows for normal loader operation during conventional use. However, when repairing damage from unstable landslides or avalanches, an operator can pilot the equipment safely from a distant or remote location.

The teleoperation system consists of an on-loader computer-based control system, an operating control computer, a remote operating unit, a full-duplex spread spectrum radio frequency communication link and actuator interfaces. Two remote operating units have been developed; a stationary on-truck workstation and a backpack style portable unit. Figure 5 shows teleoperated control with the backpack style portable control unit. The teleoperation system is capable of controlling the front-end loader with all operations including vehicle mobile controls and bucket motion controls. Several semi-automatic functions such as return to dig and travel height were implemented to speed up operations. The system has built-in safety features including reliable communication, emergency stop and automatic failure stop. The Teleoperated Front-End Loader also has been integrated with a three dimensional color video/audio feedback system. The video/audio feedback system enables the operator to regain the major senses, as to the status of the vehicle and position of the vehicle relative to the points of operation, which are lost during remote operation from a distance greater than 61 m (200 ft).

Tests and evaluations have been conducted at various sites within California, and the overall performance of the Teleoperated Front-End Loader has been very satisfactory according to user surveys. Productivity improvements also have been shown. Statewide deployment of this and two additional units will be complete by late 1997.

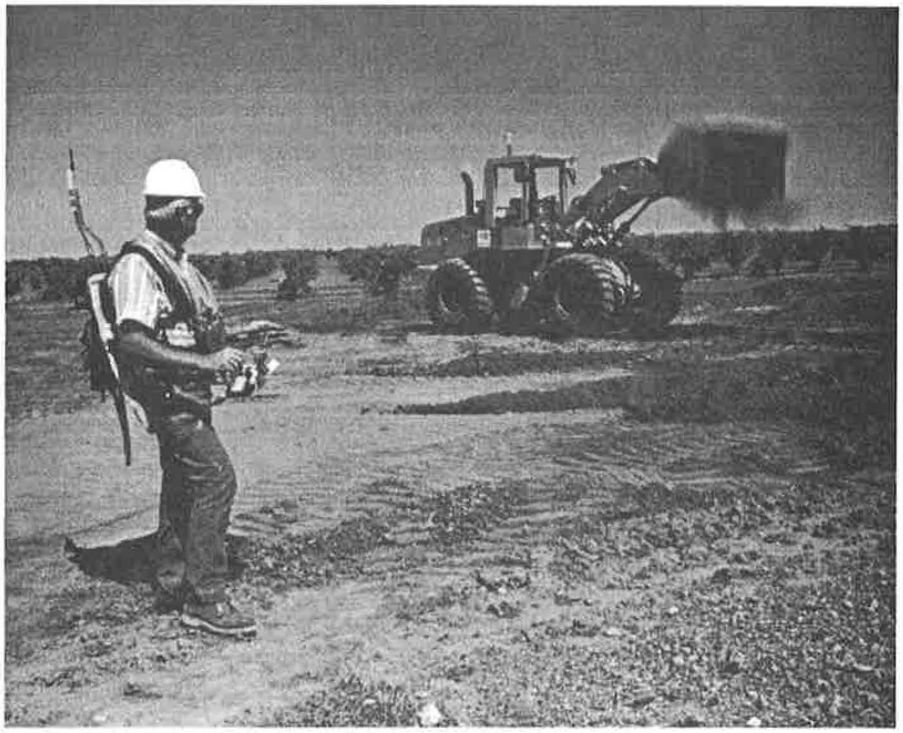

FIGURE 5 Teleoperated front-end loader.

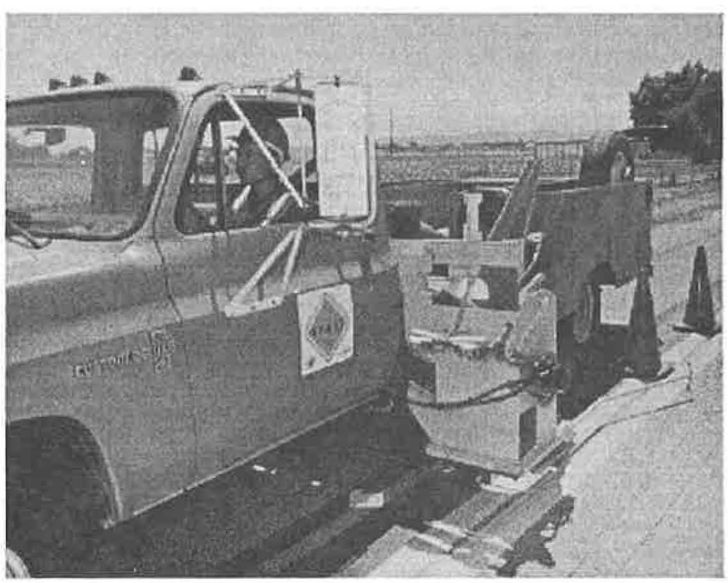

FIGURE 6 Automated machine for cone placement and retrieval.

Automated Machine for Cone Placement and Retrieval

Most highway maintenance and construction operations require a means of separating the work zone from lanes of traffic and traffic cones are one of the most common items used to delineate these work areas. Cones are one of the most readily used markers since they store in a very compact form and require no assembly prior to placement. Deployment of the cones is presently achieved by a person riding on the exterior of a modified vehicle. This person is typically either standing in a basket at the end of a truck or sitting near ground level between the axles of the customized cone body truck. Although the traffic cone is one of the most efficient methods of temporarily delineating areas of roadway, a considerable amount of manual effort is required and personnel are exposed to the hazards of traffic in addition to the physical exertion involved in handling the cones.

The AHMCT Center is developing a machine that will mechanically place and retrieve cones thus reducing worker exposure to these hazards. The automated cone machine will be incorporated onto the existing cone body, thus allowing the existing Caltrans fleet to be retrofitted with this automated equipment. Cones will be placed in the forward travel direction at speeds as high as 32 kph (20 mph). Cone retrieval will be performed in either the forward or reverse directions, at the operator's discretion, at speeds as high as 16 kph (10 mph). The machine is designed so that no on-site set up is required; deployment and stowage will be simple and fast. Furthermore, the driver's operational requirements are similar to the current approach. Under normal operation, the operator will be in the truck cab, but manual operation, as currently performed, will still be possible in the event of unusual circumstances. This application of automation significantly increases operator safety while retaining all the capabilities of the present operation. Figure 6 shows initial prototype testing.

Final field testing of the Automated Cone Placement and Retrieval Machine is slated for 1997.

SUMMARY

While considerable research has been conducted on automation and robotics for the building industry, primarily by Japanese companies, comparably little work has occurred worldwide on the application of automation and robotics to transportation maintenance and construction.[4] This paper has attempted to present a brief description of the AHMCT Center, an international leader in the application of technology to transportation maintenance and construction. The six projects described in the proceeding pages present only a subset of work conducted by the AHMCT Center and further information can be obtained by contacting the author.

ACKNOWLEDGMENT

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