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Applications of Robotics and Automation in Highway Maintenance Operations

B. Ravani[1], member ASME and T. H. West[2]

Abstract

This paper deals with the applications of Advanced Automation and Robotics in highway maintenance operations. The basic components of Robotics and Automation technologies are studied and their appropriate forms for highway maintenance applications are identified. Within each area of highway maintenance operations, maintenance tasks with high potential for the application of the Robotics and Automation technologies are then discussed.

Introduction

One of the major problems in highway maintenance operations is the potential hazard from the on-going traffic to the human workers. In California alone, maintenance personnel suffered over 4,700 work related injuries (45 of which were fatal) between 1974 and 1987 (House Resolution 1989, and Special Hearing 1989). Additional problems in highway maintenance operations include increase in traffic delays and congestions, lack of reliability and efficiency and high operating costs in the use present maintenance procedures and methods. Although Advanced Automation and Robotics (AAR) technologies have become very important in manufacturing, work in space, undersea work, work in nuclear industry and medicine, their applications in automating highway maintenance operations are only recently being exploited.

In many industrial applications, it has been demonstrated that the use of AAR technologies can lead to increased productivity, reduced hazards to human workers, more flexibility, higher reliability and lower operating costs. It is therefore natural to expect similar improvements in highway maintenance operations through the utilization of the AAR technologies. In particular, automating highway maintenance operations has the potential to greatly reduce the number of injuries and deaths to highway maintenance workers.

In response to this, the University of California-Davis and the California Department of Transportation (CALTRANS) have established the Advanced Highway Maintenance Technology (AHMT) program aimed at automating certain highway maintenance operations. This paper first gives a brief description of the basic components of this program. It then provides a functional description and classification of the components of the AAR technologies and develops the functional architechture of robotic systems suitable for highway maintenance applications. Finally a listing of several maintenance tasks, corresponding to each area of highway maintenance operations, with potential for application of AAR technologies is provided.

The AHMT Program

The AHMT program has been established to investigate application of AAR technologies in highway maintenance operation. The program has the following specific goals:

- decreasing the risk of injuries or death of highway workers by reducing exposure time to work area hazards,

[1]Department of Mechanical Engineering, University of California-Davis, Davis, CA 95616
[2]Division of New Technology and Research, CalTrans, Sacramento, CA 95819

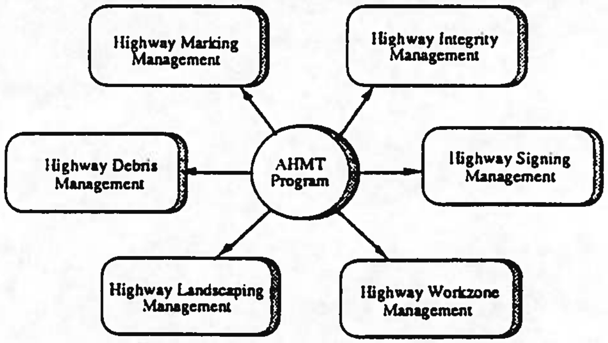

Figure 1: Areas of Highway Maintenance Operations within the AHMT Program

- minimizing hazards to the traveling public due to the slow moving highway maintenance function,
- minimizing maintenance related traffic delays by maximizing the operating speed of various maintenance tasks,
- increasing the reliability, durability and efficiency of highway maintenance functions

The AHMT program has identified several areas of highway maintenance operations for the application of AAR technologies. These areas are shown in Figure 1 and include highway marking management, integrity management, debris management, signing management, landscaping management and highway work zone management. The maintenance tasks for each of these areas and their corresponding automation requirements are described in a later section.

Advanced Automation and Robotic Technologies

The AAR technologies (see, for example, Ferrell and Sheridan 1967, Ravani and Floyd 1988, Webster and Ravani 1988) consist of several component technologies integrated together making up an autonomous, tele-operated or a supervisory controlled system. The component technologies are usually grouped together to provide the basic architecture of a generic sub-system of an automated system. The sub-systems of a present day AAR technology can be functionally characterized to include a manipulation system, a locomotion system, a external sensing system, a control and coordination system, a processing and decision making system, and a communication system including a man-machine interface. Since many highway maintenance tasks require application of other materials such as bitumin, paint, sealant or raised pavement markers to the roadway, a typical robotic system for such applications will also include a material storage and retrieval system. Although the AAR technologies have been applied to applications such as construction (Oppenheim and Skibniewski 1988) or mining (Kassler 1988) which have some features similar to those of highway maintenance tasks, their application in this area is new and only recently evolving. The sub-system architecture of a robotic system suitable for highway maintenance is shown

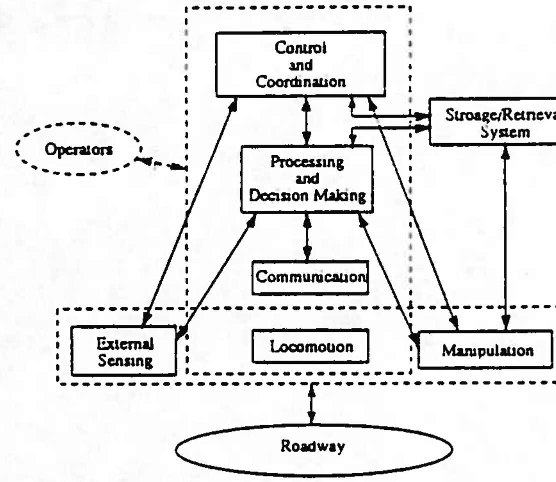

Figure 2: Functional Architecture of a Robotic System for Highway Maintenance Applications

in a functional block diagram form in Figure 2. The first three functions (manipulation, locomotion and external sensing) require interactions with the roadway. The communication function is achieved through the man-machine interface and similar to the material storage/retrieval with the operator. The level of the dependence of the control, processing and decision making functions on the operator depends on the level of the autonomy of the system. These functions become more independent of the operator as the system moves from a manually controlled system to a tele-operated system, next to a supervisory controlled and finally an autonomous system.

In such a robotic system, the manipulation system usually consists of a mechanical positioning device such as a robot arm and an end-effector or tool. The function of the arm is to position the end-effector or tool and the latter is used as an applicator to perform the task. In a robotic system for highway maintenance the manipulator can be, for example, a Cartesian arm (xy table with a servo z axis) and the end-effector may consist of specialized tool used as an applicator depending on the application. In a robotic system the locomotion function is usually achieved by a mobility unit and a navigation system. This system usually consists of sensing and computer equipment and provides mobility guidance for the mobility unit. In highway maintenance, the terrain for mobility is highly structured, a conventional truck or a towed vehicle can therefore be used as the mobility unit. In such a case, the navigation system then consists of the driver and the locomotion system is said to be human guided. The system can also be made more advanced and under supervisory control of the driver by augmenting the driver with advanced displays and sensory control schemes.

The external sensing function is usually intended to identify changes in the work environment and use the information to influence the actions of the manipulation or the navigation system. In highway maintenance, three kinds of external sensors may be needed. The first kind can be used, if necessary, to augment the information available to the driver for navigation purposes. The next two kinds will be used for the maintenance function one providing global sensing of the locations an the roadway where maintenance may be needed and the other used in the form of local sensing to plan the path and actions of the manipulation system. In more primitive forms of an automation system for roadway repair, the human operator may provide all or the navigation and global sensing functions.

The control and coordination functions are usually provided by one or more actuators, the power transmission mechanisms, controllers, feedback sensors and the control software. These functions are usually internal to the manipulation and the material storage/retrieval system. In highway maintenance some level of the control function may have to be provided by the operator in the tele-operated or supervisory controlled mode.

The processing and decision making function is usually provided by a computer system. In a fully automated system, the computer performs all the data processing and decision making functions. In a tele-operated or system under supervisory control only limited or no decision making is performed by the processing system. The human operator is used in the loop for decision making and part of the control function. The processing unit then performs much of the computation and logical operations for some of the control and coordination functions. In highway maintenance tasks, sometime it may be necessary to augment the data processing and decision making function with a data base or a knowledge base providing information on the maintenance process variables.

The communication function for a robotic system is achieved through data communication channels and protocols and man-machine interfaces. In roadway maintenance, at least in many initial implementations, the communication function is only performed through the man-machine interfaces. It will consist of displays, hand controllers, user programming systems and other means of inputting information to the robotic system and observing the actions of the system by the operator in the most transparent manner.

For a robotic and automation system to be effectively used in highway maintenance functions, it should be able to operate for a few hours before it is re-loaded. This means that proper material storage/retrieval is an important requirement for such a system. This would consist of storage tanks, canisters and other equipment integrated with material handling systems such as conveyors, feeders and hoses used to deliver different materials (e.g. adhesives, bitumin, paint, etc.) to the manipulation system.

Highway Maintenance Operations

This section provides a summary of some of the highway maintenance tasks associated with the areas of highway maintenance operations identified earlier. Some of the automation requirements for each task are also identified and provided in the summary.

1. **Highway Marking Management**
   - (a) Pavement Marker Replacement
   - (b) Paint Re-stripping
2. **Highway Integrity Management**

   - (a) Crack Sealing
   - (b) Pot Hole Filling
3. **Highway Debris Management**
   - (a) Litter Bag Pick Up
   - (b) On Road Refuse Collection
   - (c) Hazardous Spill Clean Up
   - (d) Snow Removal
4. **Highway Signing Management**
   - (a) Sign and Guide Marker Washing
   - (b) Roadway Advisory
5. **Highway Landscaping Management**
   - (a) Vegetation Control
   - (b) Irrigation Control
6. **Highway Work Zone Management**
   - (a) Automatic Warning System
   - (b) Lightweight Movable Barriers
   - (c) Automatic Cone Placement and Retrieval

Acknowledgement

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