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POTENTIAL APPLICATION OF ROBOTICS IN HIGHWAY CONSTRUCTION

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ABSTRACT

The highway construction process differs considerably from the building construction process. The unique features of highway construction enhance the potential for robotics application. This paper first anaylzes the highway construction process. Then various robotic technologies and their application to highway construction are examined. Finally, an analysis of financial performance is presented.

INTRODUCTION

The highway construction process differs considerably from that of building construction. Highway construction involves only a relatively small number of basic activities. Each of these basic activities are changed very little from project to project.

These features of the highway construction process significantly reduce one of the major barriers to the application of robotics in construction. That is, the problem of effectively applying robotics in an industry in which work activities and projects are highly unique. The very nature of road building lends itself to the standardization which facilitates implementation of robotics.

Clearly, the greatest opportunity for cost effective robotics exists when both the design and the construction process can be standardized. Highway construction can provide that opportunity.

A prerequisite to the application of robotics is an understanding of the basic construction process being considered. Therefore, this paper will first analyze the highway construction process by breaking it down into its basic components. Each of these basic components will define individually and relationally. The requirements for robotization of each work component will be developed. Then, existing robot technology will be examined with regard to specific application to highway construction work activities.

THE HIGHWAY CONSTRUCTION PROCESS

The highway construction process proceeds in a linear fashion over the length of the roadway with one operation following another. The whole process consist of a limited number of activities.

An interesting comparison can be made between the highway construction process and that of a manufacturing assembly line. In the manufacturing industry the product is moved from one fixed robot station to another along an assembly line where the same activities are repeated over and over again. The highway construction process is similar with the exception that highway is a fixed assembly line. Therefore, the robots or machines must travel along the highway assembly line.

In simple terms the highway construction process is composed of just four basic activities. Figure 1 is a schematic description of the highway construction process.

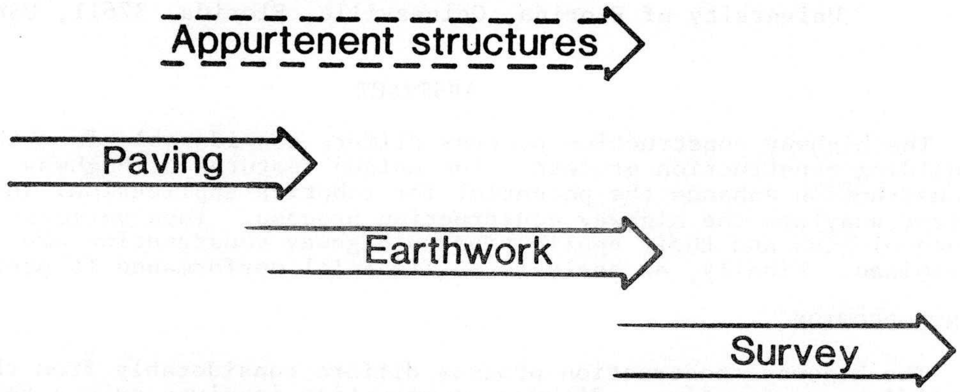

Figure 1 Illustration of the Highway Construction Process

Survey

The first step is the establishment of the alignment and elevation grade of the new roadway. This is accomplished using engineering surveying procedures to transfer the design data from the engineering drawing to the existing terrain. The survey proceeds from control reference points and results in a series of grade stakes. It is these layout stakes which serve as the position controls for the construction process. Often these grade stakes will have to be reestablished many times as the work proceeds on the roadway.

Earthwork

The heart of highway construction is the earthwork activity. This consist of reworking the existing terrain to conform to the alignment and grade required for the new road. Excess earth material is excavated and then transported along the roadway to an area requiring fill.

Excavation, hauling and dumping is typically accomplished with large earth moving equipment. Excavation is frequently performed by a excavating - hauling unit called a scraper. The scraper consists of a tractor which pulls a load carrying component called a bowl. The bottom of the bowl contains a blade which shaves off the existing earth. As the unit moves along the earth is forced up into the bowl. The operator riding in the tractor attempts to maintain a constant loading speed by varying the depth of cut. The bowl and the blade are raised and lowered to change the depth of cut. When full the scrapper hauls the material to the fill area where the earth is dumped out the back of the bowl.

Installation of earth fill consist of spreading the material by dozer tractor or motor grader and stabilizing the material by compaction. As the cut or the fill approaches the required elevation a work process called grading begins.

Grading is the process of bringing the earth road bed to the design finish elevation. Grading requires a skilled motor grader operator who must control the grader blade in order to achieve the required surface elevation within a strict tolerance. The grader operator works to grade stakes or "bluetops", which are placed in the roadway with the top of the stake set at the desired finish grade elevation of the earth.

Paving Operations

The pavement surface of the roadway is composed of either portland cement concrete or asphaltic concrete. Both materials are plant mixed and transported to the point of application. The actual installation process of both materials is similar. Both asphalt pavement and concrete pavement are spread over the road surface by a paving machine. These paving machines receive the plant mix material from the transport unit and spread the material over the roadway as the machine travels along. With both the asphalt and concrete pavers the operator must be skillful in maintaining the correct pavement thickness and smoothness.

Appurtenant Structures

The final road construction activity consist of building the related structures such as bridges, culverts, barricades, and drainage systems.

The installation of drainage pipelines resembles the highway construction process in that it is a linear operation of a limited number of activities.

DEVELOPMENT IN ROBOTICS AND POTENTIAL APPLICATIONS TO HIGHWAY CONSTRUCTION

Real Time Surveying Systems

Global Positioning Systems (GPS) now exist which can produce near real time positioning information with accuracies of up to 1 to 2 cm.[1] In the GPS system portable receivers determine relative position from a known location by monitoring navigational satellite signals. Once the known position is established light weight portable antenna-receivers can provide almost instantaneous read outs of position.

Surveying and layout remains an operation which must precede construction operations. In fact, because of the nature of the earthwork, process, layout often must be repeated as the earthwork proceeds. Therefore, improvement in survey efficiency will also improve the overall efficiency of the construction process.

Computerized Control of Plant Operations

Highway construction is dependent upon plant produced materials. Both asphaltic concrete and portland cement concrete are produced from central plants and transported to the point of installation.

Computerized control of plant operation has long been used in the manufacturing industry. The application of this technology to highway construction produces several benefits. Plant productivity and efficiency is improved. Additionally, quality control of the product is enhanced.

Finally, the computer control system can provide accurate real-time production and quality control records.

Microprocessor Engine and Transmission Controls

Robotics can provide a significant improvement to the operation of earth handling equipment. The overall efficiency and productivity of the machine is largely determined by the operators ability to control the machine's power (through throttle and gear changes) and at the same time manipulate the operating component to achieve the desired effect. Microprocessors integrated with the equipment's manual controls accurately and efficently match power to work load.

A clear example of the benefits of this application can be seen with scraper operation. As the scraper bowl fills the force required to push the earth into the bowl increases. In order to maintain optimum thrust and constant velocity the operator must continually adjust the depth of cut by raising (or lowering) the bowl and its cutting blade. Achieving an optimum condition is very difficult and requires considerable operator experience.

An automatic control system for a scraper monitors the machines velocity during loading and automatically adjust the depth of cut, and thrust to maintain optimum performance.

Tests of this type of automatic control sytem for scrapers have shown that the test scrapers "filled their bowls efficiently and cut smoothly and evenly."[2]

Laser Position Location and Control Systems

Laser control systems improve the earth handling equipment process by providing an automatic level control. The laser control system consist of a laser transmitter which is usually tripod mounted. The transmitter emits a rotating laser beam which forms a flat reference plane of light. A sensor mounted on the earth moving equipment detects the laser beam. Once the sensor target and the equipment's cutting blade have been calibrated, blade elevation can be automatically controlled with relation to the laser elevation reference.

Control can also be performed manually by the operator who watches a visual position indicator and adjusts the blade elevation. In the automatic mode the sensor signal is directed to a microprocessor which in turn automatically activates hydraulic controls to adjust blade position.

Figure 2 is an illustration of a laser position control system. Figure 3 is a photograph of laser receiver mounted on a motorgrader.

Performance improvements can be significant. One such system resulted in an increase daily production of a single motor grader from 30000 f^2 ($3000m^2$) to 200000 $f7^2$ ($20,000m^2$).[3] In addition, laser control systems have increased the operational range of certain equipment. Crawler tractor-dozers have been able to perform fine grading operations (a task which they can not normally perform).[4]

In highway construction the laser system provides a flat reference plane. However, few roadways are flat. Highways generally follow at least to some degree the curvature of the exsiting ground. Therefore, the finish surface of the road is usually curved and not flat.

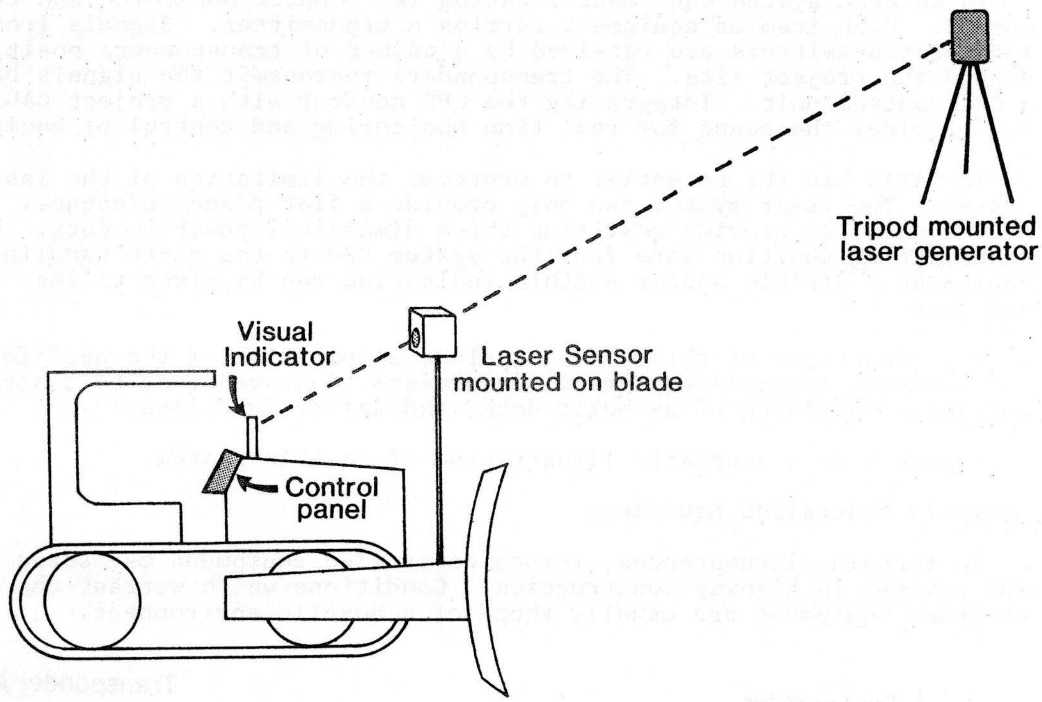

Figure 2 Illustration of Laser Position Control System[5]

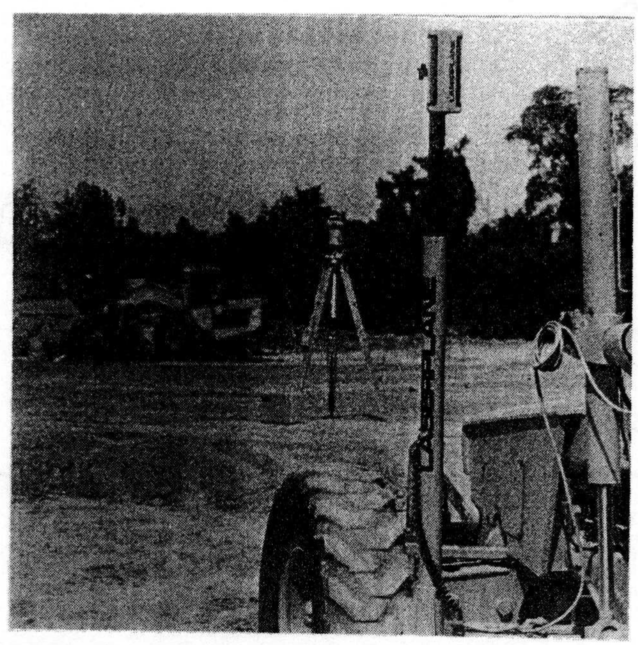

Figure 3 Motor Grader Operating with Laser Position Control System (Photograph Courtesy of Spectra-Physics)

Automated Position and Control Systems (APAC)[6]

In an APAC system equipment location is computer monitored and recorded. Each item of equipment carries a transmitter. Signals from the locator transmitters are received by a number of transponders positioned around the project site. The transponders retransmit the signals back to a CPU control unit. Integrating the CPU control with a project CAD system provides the means for real time monitoring and control of equipment.

The APAC has the potential to overcome the limitation of the laser system. The laser system can only provide a flat plane reference. The APAC system can provide real time three dimensinal position data. By transmitting position data from the system CPU to the earth handling equipment a visible and/or audible indication can be given to the operator.

The advantages of this system include elimination of the need for layout staking, improved equipment performance, improved quality control, automatic recording of as-built data, and safety functions.

Figure 4 is a schematic illustration of an APAC system.

Remotely Controlled Equipment

In certain circumstances, remote controlled equipment may serve a useful purpose in highway construction. Conditions which warrant the use of unmanned equipment are usually those of a hostile environment.

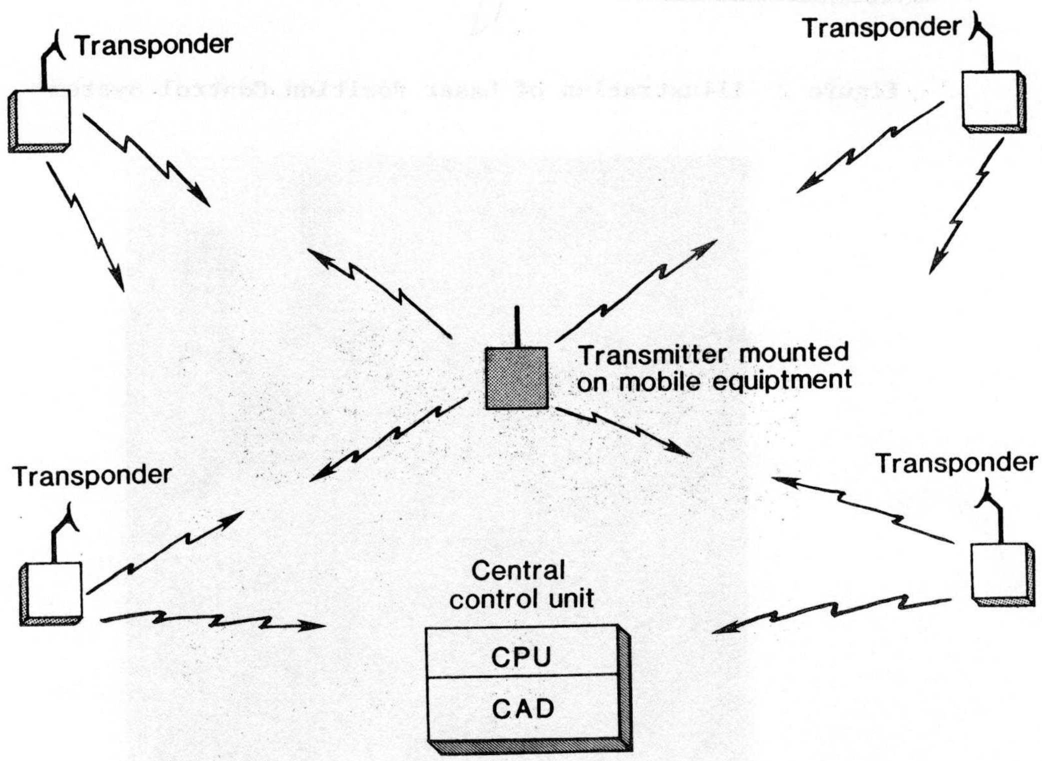

Figure 4 Schematic Illustration of an APAC System[7]

Deep trench excavation and pipe laying are examples. Deep trench excavation presents a hazard for workers who must enter the excavation. Unless expensive shoring is provided the danger of cave-ins can be high. Therefore, a machine which can operate unmanned is desirable.

Similar machines have been developed for under sea operations for tunnelling operations. A 160 ton remotely control rock excavator was used to excavate a four foot deep trench across the floor of the English Channel between England and France.[8] This special piece of equipment, which was controlled from a barge above, was able to complete the project ahead of schedule.

Therefore, when the economic and risk factors dictate, remotely operated equipment will certainly be developed and employed.

ECONOMIC FEASIBILITY OF ROBOTIC DEVELOPMENTS IN HIGHWAY CONSTRUCTION

All engineering developments which are expected to be used by a competitive industry must pass a critical financial test. The economic benefit of the product must exceed its costs.

Robotization of highway construction has a clear economic advantage over the application of robotics to building construction. Building construction remains a relatively labor intensive process. Robot applications in building construction are evaluated in terms of manpower savings. The initial investment costs are high because a complete new robot machine must be developed.

On the other hand, highway construction has evolved into an equipment intensive process. Robotics applications in highway construction are primarily aimed at improving the performance of equipment. Because of the high hourly operating cost of the equipment, even small improvements in productivity will result in substantial savings. Furthermore, adaptive automatic controls for existing equipment are considerably less expensive than the cost of developing a complete robotized machine.

The economic advantage of applying adaptive robot systems to existing construction equipment can be seen in the following example.

Value Estimation Example

One way to evaluate any potential investment is to calculate its present value. In this instance the value will be calculated as the present worth of the direct savings realized from implementation of the robot system minus the associated expenses.

The following equation can be used to determine present value of an adaptive robot system.

$$V = [(CNS) - (M + D + O)] \frac{(1 + \ )^n - 1}{(1 + \ )^n} \qquad (1)$$

V = Present value of system
C = Host equipment cost per hour
N = Equipment operating time in hours per year
S = Productivity savings
M = Maintenance cost of robot system per year
D = Depreciation cost of robot system per year
O = Operating costs of robot system per year
n = Economic life of robot system in years
= Interest rate

Consider a Laser Position Control installed on a motorgrader. System initial cost is $12,000.00.

Input data,

C = $42.00/hr
N = 1500 hrs.
S = 0.20 (20% productivity improvement)
M = $2,400.00/yr
D = $2,400.00/yr
O = $0.00 (System does not change operating cost of host equipment)
n = 5 yrs.
= 10%

$$V = [(42 \times 1500 \times .20) - (2400 + 2400)] \frac{(1 + .10)^5 - 1}{.10(1 \quad .10)^5}$$

$$V = [12600 - 4800]\ 3.791$$

$$V = \$29569.80$$

This present value compares very favorably with the investment cost of $12,000.00.

CONCLUSION

The potential for application of robotics to highway construction is particularly great because of the unique nature of the highway construction process. This paper has focused on the construction process and the elements which facilitate implementation of robotic technology. Table 1 provides a summary of robotic applications in highway construction.

Several robotic systems are now in use in highway construction and these systems are making money for the contractor. Adaptive control systems will continue to lead the way because they provide the highest return for lowest investment cost.

Possible the largest improvement to the overall construction process will come with the APAC technology. The benefits from a completely integrated control and data base system are practically limitless.

Notes

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4. Ward, p. 7.

5. Tatum and Funke, p. 27.

6. Beliveau, Yvan J., (1987), "Global Data Base for an Automated Construction Industry," Civil Engineering in the 21st Century, ASCE.

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8. London Press Service, (1983), "Rock Trencher Rips Channel," ROBOT/X News Vol. 2.

Table 1

Summary of Robotics Applications in Highway Construction

Technological Development	Construction Activity	Robotic Application	Benefits to Construction Process
Satellite Positioning Systems and Mircoprocessors	Surveying and Layout	Global Positioning System (GPS)	More Efficient Survey and Layout Activities
Microprocessor Controls	Plant Operations	Computerized Control of Central Plant Processes	Improved Quality Control, Increased Production, Automatic Record-Keeping
	Earth Handling Equipment	Automatic Control of Thrust	Increased Production, Improved Quality Control, Improved Efficiency
Laser Leveling Systems	Excavating and Grading	Laser Position and Control System (LAPCOS)	Increase Production, Improved Quality Control, Reduced Layout Effort
RF Transmitted Position System	Earth Handling and Paving	Automated Position and Control System (APAC)	Increase Production, Improved Quality Control, Reduced Layout Effort, Automated As-Built Recording, Safety Controls
Remotely Controlled Systems	Any Equipment Performed Activity	Remote Controlled Specialty Equipment	Safe Operation in Hazardous Environment Economy when safety costs are considered

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