Teleoperated Pipe Manipulation

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ABSTRACT

Excavation, and in particular trenching using backhoes, represents a hazardous working environment for humans. Many hazards exist including trench walls which can collapse, heavy objects which can be accidentally dropped into the opening, and buried utilities that are damaged during the operation. The objective of this paper is twofold: (1) present the concept and development of a spatially integrated pipe-laying system, and (2) prove the technical feasibility and effectiveness of such a system under field conditions. A teleoperated device has been developed which would perform the pipe-laying operation. The pipe-manipulator was integrated with a backhoe excavator, control units and a laser based position measurement tool. An innovative technology for remotely controlling large concrete pipe laying was tested. This technology is considered a key component for improving workers' safety and productivity.

Introduction

Safety has become a major concern in the construction industry over the past few decades. According to the statistics (Bureau of Labor Statistics, 1996), the number of fatalities in the construction industry in 1994 was 1,027. This number equates to 16% of the total fatalities from all industries and indicates that the construction industry has the highest fatalities. Another statistic shows that the construction industry employs approximately 5% of the industrial work force, but has generally accounted for nearly 20% of all of the unintentional deaths (National

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Safety Council, 1996). The fatality rate in the construction industry has increased by 4% in a 2 year interval from 1994 to 1996. An analysis of National Institute for Occupational Safety and Health (NIOSH) data shows that excavation cave-ins were the cause of about 1,000 work-related injuries each year. Of these injuries, 140 resulted in permanent disability and 75 in death.

Considering these statistics, it is not surprising that trenching and pipe-laying has been listed as one of the most important applications of advanced technologies in a report published by the Federal Highway Administration (Federal Highway Administration, 1995). The report was the result of an extensive study that included two workshops: site visits of automation experts, and a life-cycle cost-benefit analysis. Respondents of a survey rated *"the impact of improved safety in trenching and pipe-laying operations"* as the most important of six technologies proposed by a panel of experts that had investigated the needs and potentials of advanced technologies in highway construction and maintenance.

The objective of this paper is to discuss the teleoperated pipe manipulator and analyze the effectiveness of the system under field conditions.

Trenching and Pipe-laying

A trench is defined as a narrow (in relation to its length) excavation made below the surface of the ground (US Department of Labor, 1989). Since the trench normally requires narrow and deep excavation, the working environment is always hazardous. Current methods of trenching and pipe-laying involve construction workers excavating trenches to the required width and depth using surveying methods and approximation to control depth and direction. A pipe worker, then enters the trench in order to bed the pipe, joint them, and finally align the pipes together. The pipe is placed in the trench using a crane or an excavator and connections are made either mechanically or by hand depending upon the type and size of pipe to be laid.

One of the most commonly used pieces of equipment for trench excavation and pipe-laying is the backhoe excavator due to its various capabilities. Since equipment operators cannot see inside the trench, additional observers and pipe workers are required. An observer is required to act as a communicator between the two parties. Under this situation, the workers may have idle time waiting for other duties. For instance, the pipe worker is idle while the equipment operator is lifting and moving a pipe

Diverse support systems to prevent trench cave-ins, such as shoring, bracing, shield (trench box) and sloping have been introduced and applied in trench excavation and pipe-laying operations. Figure 1 shows two different typical support systems. Even when support systems are used, the danger of cave-ins exists due to the nature of the soil in the sidewalls and unexpected circumstances. A new technical approach such as a teleoperated system consisting of a mechanical pipe-laying device and a control program has the possibility of improving productivity, safety, and quality of the performance of trenching and pipe laying operations.

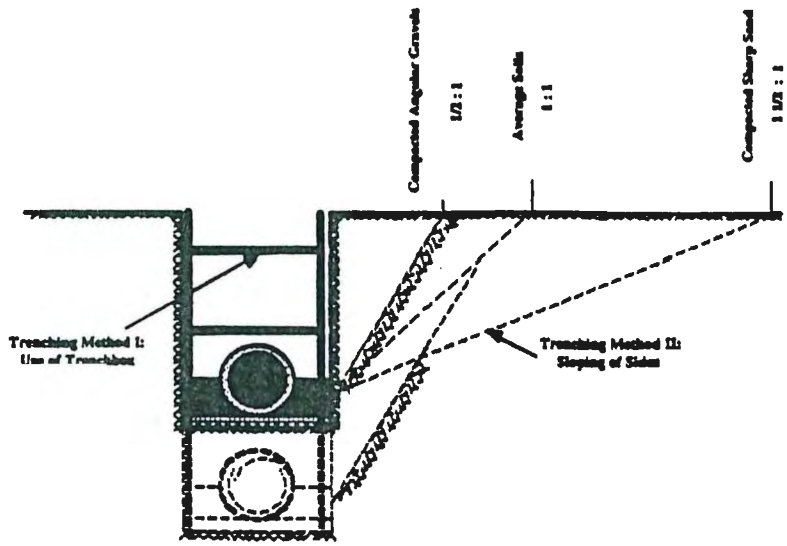

Figure 1. Support system for trench

Teleoperation

Industrial robots have been used for the past few decades. Although many robots are controlled by computers, they are not as intelligent as human beings. Currently, there is challenging research being done on machine intelligence. In an unstructured working environment, especially one that is hazardous or harmful to humans, the man-machine interface system is used to perform the tasks. The basic concept of a man-machine interface for trench excavation and pipe-laying is to have the operator stay in a safe area and guide the machine intelligently, while the machine works in the hazardous environment. The term "teleoperation" is used to describe the activities performed by mechanical devices at a remote site under remote control by an operator (Bejczy, 1980). Teleoperation technology has been advanced through the introduction of various sensors, computers, automation, man-machine interface devices and remote control.

System Configuration

A teleoperated pipe manipulation system was developed in order to protect the construction worker(s) from cave-ins during trench excavation and pipe-laying operations. First of all, a pipe manipulator was developed which attaches to the bucket of a backhoe excavator for pipe-laying in a trench. A control system including CAD, a spatial positioning system, and a laser beam were developed and integrated for an operator to be able to remotely control the operation.

A conceptual layout of the teleoperated pipe manipulator is shown in Figure 2.

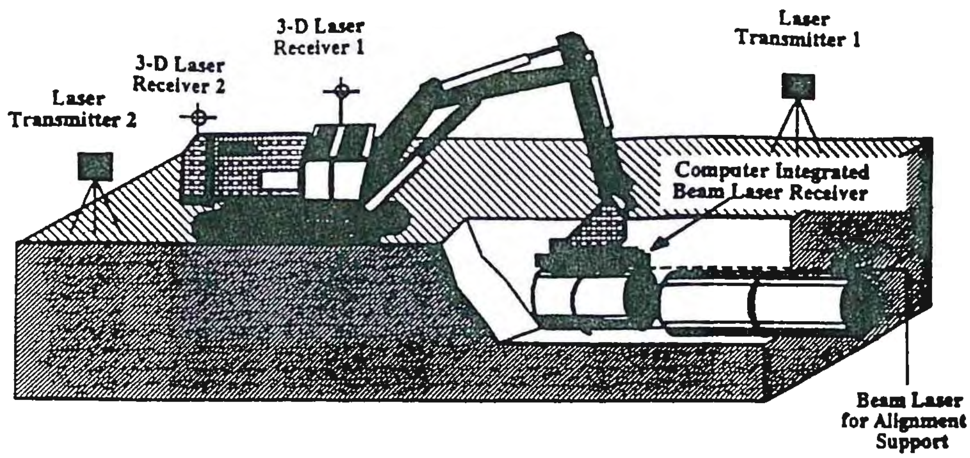

Figure 2. Schematic of teleoperated pipe manipulator with laser guidance (Bernold and Huang, 1995)

The manipulation and final positioning of large concrete pipes in the trench requires several important capabilities. First, the hardware has to be very robust and heavy duty since such pipes are generally heavy. Second, the O-ring compression joints require a linear insertion of the new pipe element into the bell of the previously laid pipe. Third, proper laying of pipes to meet line and grade requirements make it necessary to utilize a beam laser. Fourth, the release mechanism for the pipe has to be remotely controllable.

The pipe manipulator was equipped with two degrees of freedom. One is a rotational joint, which is capable of rotating the upper part of the pipe manipulator. Another is a linear joint on the lower part which has a translational motion for pipe alignment. In other words, the manipulator is made up of a heavy duty bearing and a linear track supporting a carriage with four wheels and a hydraulic cylinder that provides a linear motion capability. Each pipe segment is being held by one cable which is operated via an electric winch mounted on the carriage. A hydraulic motor and a chain allow the attachment to be rotated 360 degrees so that the excavator operator is able to insert the bottom of the bucket into the cantilevered "hook".

Not visible in Figure 2 are the hydraulic lines and the electronic cables which provide the operator with the data from the laser receiver. The laser receiver is mounted on the linear track and is capable of sensing the position of a laser that hits its plane surface. The laser helps the operator to align the pipes.

Field Tests

Figure 3 presents the pipe-laying process. First of all, a trench must be excavated in order to lay the pipe into the ground. Then, the backhoe-excavator-mounted pipe manipulator performs the procedure of picking a pipe, delivering it to the trench, lowering and lining up the pipe section with the already placed pipe section. Once the pipe section is in place, a quick-release handle is used to release the cable attachment to remove the pipe manipulator from the pipe section thus finishing the procedure.

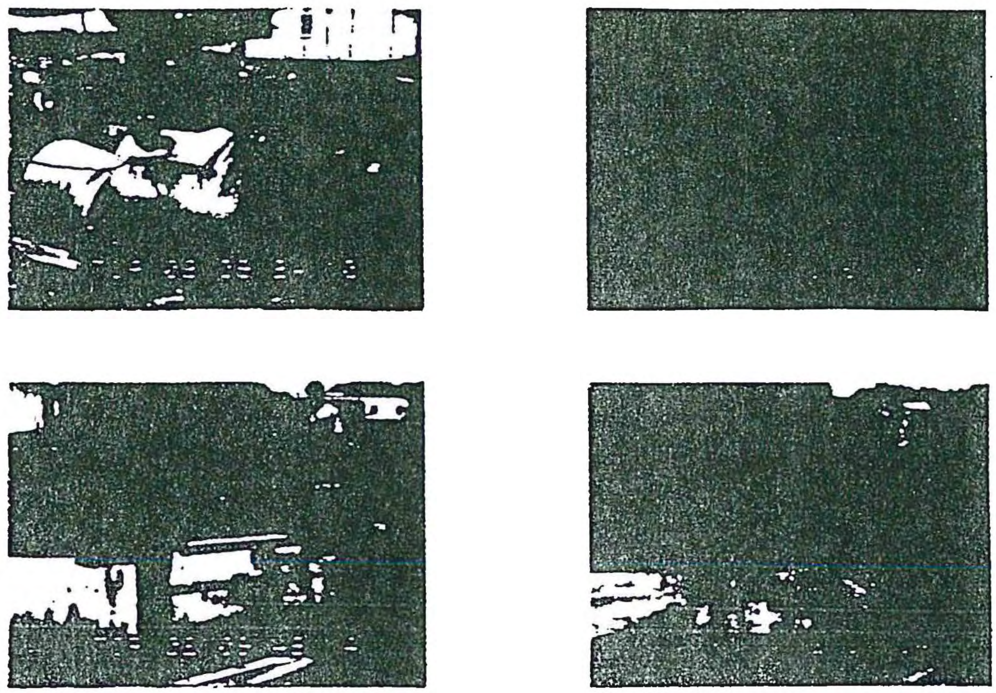

Figure 3. The sequence of the pipe-laying procedure

System Upgrading

The original pipe manipulator has been modified to improve the ease-of-use and reliability. During previous testing it was found that it was not very easy to attach the pipe manipulator onto the bucket of the backhoe and to secure it.

An upgraded pipe manipulator is designed in AutoCAD as shown in Figure 4. The amount of clearance available to insert the bucket has been increased to 10.25" (26 cm) from 6" (15.2 cm) in order for the bucket to fit more easily and bladders were mounted to support the bucket from slipping off during operation. The basic principle of the bladder system is that hydraulic fluid is introduced into the unit through the bladder intake. This causes the bladders to inflate clamping the pipe manipulator to the bucket. A rubber plate of 1" (2.54cm) thickness is also attached both at the bottom of the upper part of the cantilevered hook and on the top of the steel plate over the bladders to eliminate slippage. Additionally, a locking mechanism on the back of the pipe manipulator has been designed as a mechanical stop to prevent the pipe manipulator from sliding off the bucket. A rotary actuator will rotate steel bars toward the back of the bucket.

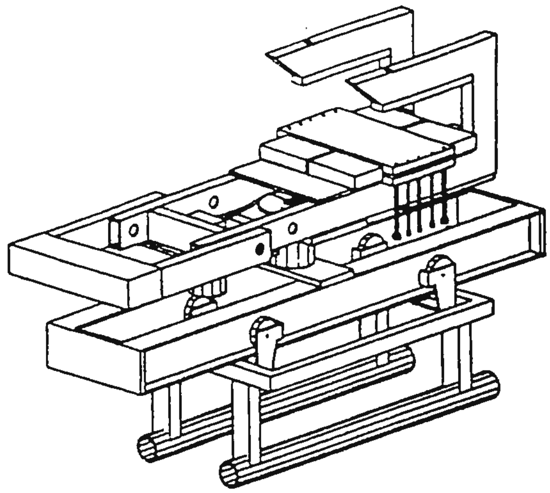

Figure 4. Schematic overview of pipe manipulator

Figure 5 shows the laboratory setup of the pipe manipulator mounted on a concrete pipe. A hydraulic manifold distributes hydraulic fluid into the 4 different actuators or cylinders. A pressure relief valve is used to reduce the source hydraulic pressure to the working range of 1000 psi (6.895 mPa). Proportional valves and plugs are used to control the actuation of each actuator or cylinder via computer. A directional valve with an additional pressure reducing valve is used for the bladder system because the allowable maximum pressure is 100 psi (689.5 kPa).

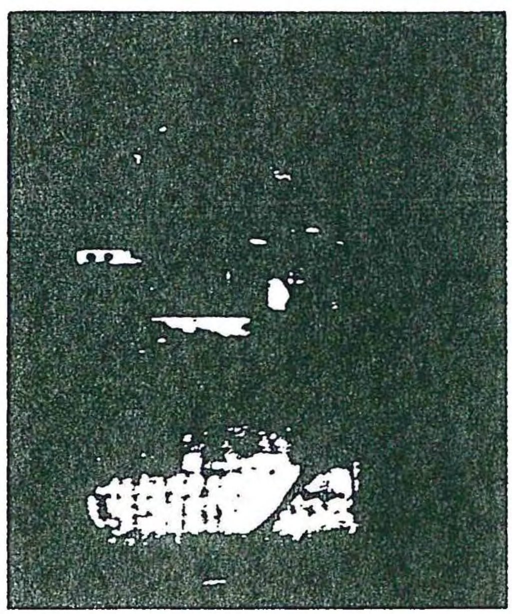

Figure 5. Overview of pipe manipulator

Micro cameras are mounted to improve the man-machine interface. This system allows the operator to have real time visual control for the final alignment of the pipe joint. A transmitter sends a video signal to the receiver via an RF link and the operations of pipe manipulator are displayed on a screen for the operator to view. To allow for high precision placement of the pipes, a laser system also is used to make sure that the grade is correct.

Conclusions

An experimental pipe manipulator was developed and tested. Research is in progress to improve the teleoperated system. Future work will concentrate on interfacing the pipe manipulator, excavator, CAD, spatial positioning system, video, and a laser system.

Acknowledgements

This publication was supported by Grant Number 5R01 CCR413051-02 from the National Institute of Occupational Safety and Health. Its contents are solely the responsibility of the authors and do not necessarily represent the official view of the National Institute for Occupational Safety and Health.

References

1. Bejczy, A.K., (1980). Sensors, Controls, and Man-Machine Interface for Advanced Teleoperation, Science, Volume 208, Number 4450, June, pp. 1327-1335.
2. Bernold, L.E., Huang, X., (1995). CAD-Integrated Real-Time Control for Robotic Excavation and Pipe-Laying: Development and Field Testing, FHWA Final Report: August 94 -August 95.
3. Federal Highway Administration, (1995). Robotics Application to Highway Transportation, FHWA-RD-94-094, National Technical Information Service, Springfield, Virginia.
4. National Institute for Occupational Safety and Health, (1995). Preventing Deaths and Injuries From Excavation Cave-Ins, NIOSH Alert, DHHS Publication No. 85-110.
5. National Safety Council, (1996). Accidental Facts, Statistics Department, Itasca, Illinois.
6. Bureau of Labor Statistics, (1996). Fatal Workplace Injuries in 1994: A collection of Data and Analysis; Report 908, Safety & Health Statistics.
7. US Department of Labor, (1989). Federal Register, Occupational Safety and Health Administration, 29 CFR Part 1926, Occupational Safety and Health Standards - Excavation; Final Rule.

Demsetz, Laura A.
Robotics '98 : Proceedings of the 3rd ASCE Specialty Conference on Robotics for Challenging Environments, Albuquerque, New Mexico, April 26-30, 1998. -- American Society of Civil Engineers, 04/1998.

ISBN 0-7844-0337-6 Trade Cloth. : $59.00.

1. ROBOTICS. 2. TECHNOLOGY / Robotics. I. Bryne, Raymond H.. II. Wetzel, John P.. III. Title.

98-4521
21-3.A83 1998