



Improving the Safety and Efficiency of Roadway Maintenance Phase I: Developing a Robotic Roadway Message Painter Prototype

Final Report

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16. Abstract (Limit: 250 words) A large-scale prototype for a robotic roadway message painter was developed, built, and tested. The system is a gantry-style robot capable of painting a four-by-eight-foot area and is based on off-the-shelf linear motion components, readily available motion control hardware, and commercial operator interface software. The system is mounted on a modified trailer that can be manually rolled around for positioning or towed behind a vehicle. The system is equipped with a standard automatic paint head and airless paint pump. Software was developed for the system that enables it to paint a variety of characters and symbols on the roadway. An operator interface was also developed that allows an operator to easily select the painting operation to be conducted and to monitor and control the actual painting process. The software resides in a laptop computer that communicates with the robotic painting system in real-time using a dedicated Ethernet connection. The system was used to determine the feasibility of painting with or without stencils and to determine many design parameters for the eventual development of a commercially viable system for painting symbols and messages on roadways. It is expected that the system will eventually enable states, counties, and municipalities to improve the safety, productivity, and flexibility of their pavement marking operations.			
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Executive Summary

This project was undertaken in response to a problem statement which was submitted by the Minnesota Department of Transportation. The goal of the project was to develop a large-scale functional prototype of a robotic roadway message painter that could be run by a single operator, and to develop software to enable the device to automatically paint various messages and symbols on roadways. The prototype developed under this project was used to determine the best paint application technique, including the possible use of stencils that are automatically deployed and retrieved. The device would also be used to determine the effects of different variables on painting speed and quality, and to demonstrate the feasibility of painting messages and symbols on a roadway.

The work for this project was broken down into functional areas, and each of those areas was further subdivided into specific tasks. First, a study was undertaken to determine the feasibility of using automatically deployed stencils rather than a purely robotic painting system. The results of this study were that the expense of providing a system for automatically deploying and retrieving stencils was not justified by the benefits, and that a stencil-free robotic painting system would have more benefits at lower cost. The device was then designed and constructed with that in mind. The mechanical work consisted of designing and constructing the painter structure, specifying, purchasing, and installing the linear motion components, and specifying, purchasing, and installing the paint delivery system. The electrical work consisted of designing, specifying, and purchasing the servo control system and electrical power supply, and installing these components on the structure and connecting them to the motion control components to form a functional robotic system. The software work consisted of developing motion programs for each character or symbol and developing an operator interface for the device.

Tests were run to determine the optimal values for several design parameters. The results of these tests helped to determine the maximum paintable area, optimal painting speed, optimal painting width, optimal paint pressure, actuation air pressure range, and maximum power demand for the unit. Finally, all of the motion programs were tested to demonstrate the capabilities of the machine to paint letters and symbols on the roadway. Programs were written and tested for all of the letters of the alphabet and for the words STOP, SLOW, TURN, and XING. Programs were also written for straight, left turn, right turn, and straight/left combination and straight/right combination arrows. In addition, programs were written for painting symbols, including handicap parking, bike lane, and railroad crossing markings.

The device clearly demonstrated the feasibility of using robotics to paint roadway markings, and has helped to determine many of the design parameters necessary to develop a commercially viable unit. The device can be controlled from a laptop computer at a safe distance by a single operator. Expected benefits of the commercial deployment of such a device include improved operator safety, improved productivity, and improved flexibility in roadway marking operations.

Chapter 1: Introduction

This project was undertaken in response to the following problem statement which was submitted by Randy Resnicek of the Minnesota Department of Transportation:

Placing messages onto the roadway surface including stop-walk messages or left or right turn arrows is accomplished using stencils and rollers. Can a robotic message painter be developed whereby messages could be applied automatically from an operator position?

This project built on the success of a previous NATSRL seed grant project which demonstrated that robotic painting of roadway symbols was feasible. The goal of this project was to develop a large-scale functional prototype of a robotic roadway message painter that could be run by a single operator, and to develop software to enable the device to automatically paint various messages and symbols on roadways. The device would then be used to determine the best paint application technique, including the possible use of stencils that are automatically deployed and retrieved. The device would also be used to determine the effects of different variables on painting speed and quality, and to demonstrate the feasibility of painting messages and symbols on a roadway.

The Seed Grant Project

A study was completed in June 2008 in order to demonstrate the feasibility of using a robotic actuator to paint roadway markings. The system used an existing robot arm, which was equipped with a standard pavement striping paint sprayer for the duration of the study. This combination was capable of painting symbols, letters, and numbers up to a maximum size of approximately 3 ft. x 3 ft. Software was developed for the system that enabled it to paint a variety of characters and symbols on a simulated roadway. The system was successfully demonstrated in actual painting operations by painting on heavy textured paper to simulate painting on pavement.

Literature Review

Two projects with similar objectives were found in the literature, one at the Advanced Highway Maintenance and Construction Technology Research Center at the University of California Davis [1] and the other in the Department of Mechanical Engineering at Korea University [2].

U. C. Davis has two systems under development, one that uses a gantry-style robot housed in an enclosed trailer. This system is primarily used to paint photogrammetry symbols (a white X on a black background) on the pavement to support aerial surveys. The other system under development is called the Big Articulated Stenciling Robot, and consists of a large computer-controlled hydraulically powered arm that extends from the back of a truck. The arm can reach over 14 feet, and with it a single operator can conduct automated pavement marking operations from the cab of the truck.

The Korean system consists of a gantry robot with an extended transverse arm that allows lane-width painting. It is also capable of conducting automated pavement marking operations with a single operator.

Expected Benefits

The initial benefits of this research will be in the area of roadway painting, but these benefits could be expanded in the future to include other roadway maintenance areas like automated crack-filling and automated pothole repair. The expected benefits are as follows:

- Improved safety: Fewer workers will be exposed to the work zone for a shorter period of time, and the system can be operated from a safe distance.
- Improved productivity: More rapid painting operations will be conducted with less labor
- Improved flexibility: The system may not be limited to stencils but could possibly be able to paint virtually any character or symbol on the roadway.
- Future benefits: Expansion of the techniques to other areas like automated crack-filling and pothole repair.

Intellectual Property Protection

The Office of Technology Commercialization at the University of Minnesota has determined that, although the robotic roadway painter concept does not appear to be patentable, it is still worth protecting since the technology could very likely be licensed and marketed to potential manufacturers. For this reason this report is focused on the results of the research rather than the details of the design, materials and construction of the painting device.

Chapter 2: Methodology

The work for this project was broken down into functional areas, and each of those areas was further subdivided into specific tasks. Table 1.1 shows the work breakdown for the project. The work done in each area is detailed in the sections that follow.

Table 2-1: Work Breakdown Structure

Area	Tasks
Stencil study	Determine the practicality of, and the need for, a system that could automatically deploy and retrieve stencils
Mechanical work	Design and construct painter structure Specify, purchase, and install linear motion components Specify, purchase, and install paint delivery system
Electrical work	Design, specify, and purchase servo control system and electrical power supply Install on the structure and connect to motion control components to form a functional robotic system
Software work	Generate motion paths for characters and symbols Develop operator interface
Testing	Test device for proper operation Test paint nozzle configurations Determine capabilities of the device

Stencil Study

A study was undertaken to determine the feasibility of using automatically deployed stencils rather than a purely robotic painting system. The results of this study were that the expense of providing a system for automatically deploying and retrieving stencils was not justified by the benefits and that a stencil-free robotic painting system would have more benefits at lower cost.

Mechanical Work

The mechanical work consisted of designing and constructing the painter structure, specifying, purchasing, and installing the linear motion components, and specifying, purchasing, and installing the paint delivery system.

Structure: After considering several alternatives it was determined that the prototype would be built on a trailer frame. This solution would result in the lowest cost and still give good portability and maneuverability for testing purposes. After considering several trailer designs a decision was made to purchase a folding trailer kit from Red Trailers (Figure 2.1), and to modify that kit as needed to provide an adequate structure for the painter.



Figure 2-1: SJ-8531 Trailer

(<http://www.redtrailers.com/images/BlackTrailerFront.jpg>)

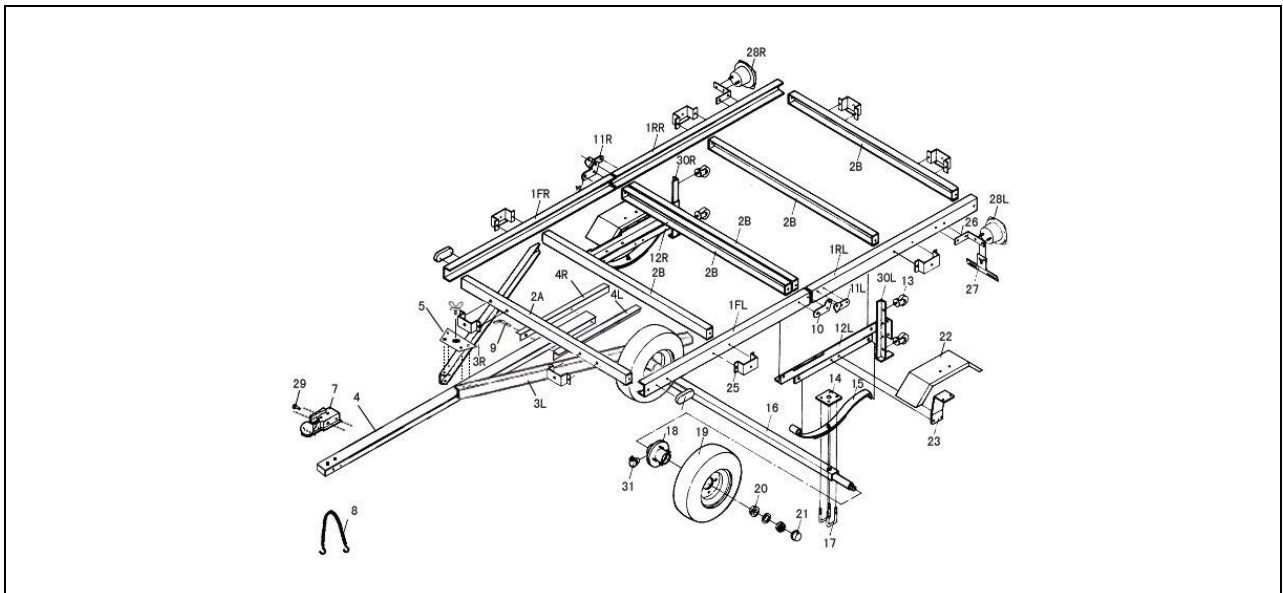


Figure 2-2: Trailer Kit Exploded View

(<http://www.redtrailers.com/manuals/SJ-8531.pdf>)

Purchasing a kit rather than a competed trailer had major advantages. We could avoid any disassembly or deconstruction, and we could use the components of the kit (Figure 2.2) in a way that better suited our project.

The trailer required major modifications in order to meet our needs. The painter prototype required an opening of over 4 ft. by 8 ft. in the body of the trailer, so major structural elements had to be removed and the frame had to be stretched. The stretch was accomplished by adding lengths of 1.5” x 3” rectangular steel tubing to the frame. A superstructure was added to counteract the effects of the removal of the structural cross-members, and this also allowed the trailer axle to be moved to the extreme rear of the trailer frame to maximize the available painting area.

Linear Motion Slides: Several alternative linear motion components were considered and the decision was made to proceed with ordering Voyager belt-drive linear motion slides from Techno-Isel (Figure 2.3). It was felt that these components provided the best price and performance combination for the project. The slides were ordered complete with servo motors, encoders, speed reducers, and mounting hardware to simplify the remaining design and assembly tasks.

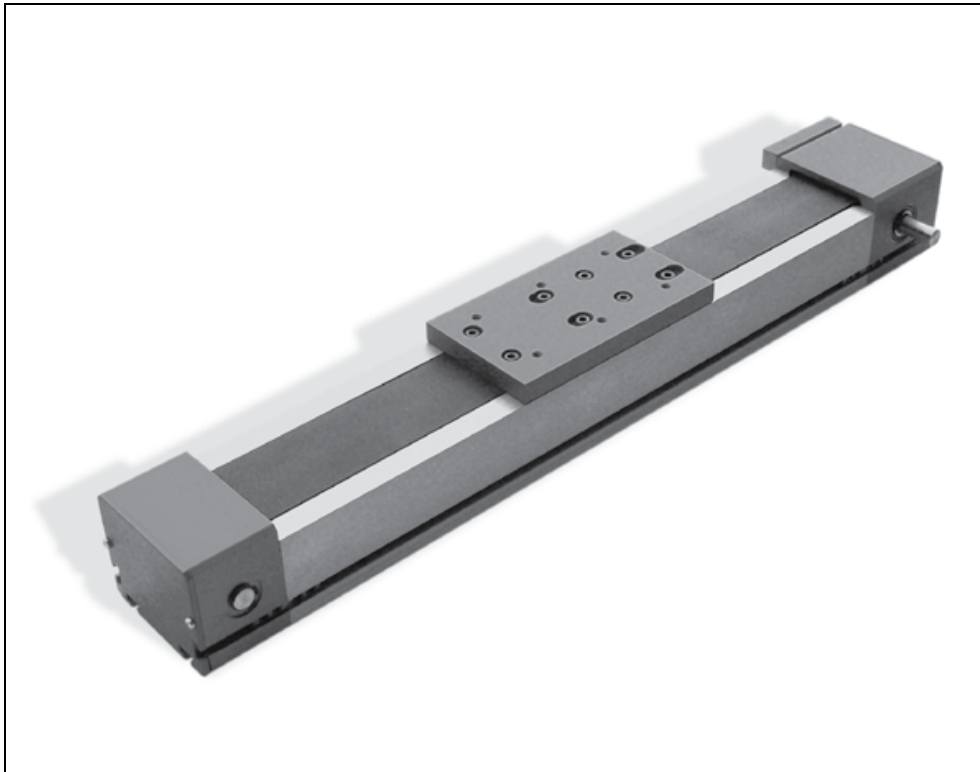


Figure 2-3: Voyager VB1 Belt Slide
(<http://www.techno-isel.com/tic/Catdas/PDF/Voyager01.pdf>)

Paint Delivery System: As with other aspects of this project, several alternatives were considered to determine the best paint delivery system. Because of our need to rapidly turn the paint on and off, and our desire to have minimal overspray, it was decided that an automatic airless spray gun would be the best solution. This led to a decision to purchase a Graco Magnum

X7 airless paint pump (Figure 2.4) and a Graco AL series spray gun (Figure 2.5). Because the automatic spray gun is air-activated, a small (3-gallon) Husky air compressor was also purchased.

 A blue and silver Graco Magnum X7 airless paint pump. It features a large blue hose reel on top, a pump handle, and a spray gun attached to the side. The unit is mounted on a silver metal frame with two large black wheels and a smaller front wheel.	 A black and silver Graco AL series airless spray gun. It has a cylindrical body with a spray gun nozzle at the front and a handle at the back. The body is marked with 'AL' and other technical specifications.
<p>Figure 2-4: Graco Magnum X7 Pump (http://magnum.graco.com/products/M_Pages.nsf/Webpages/0MagnumX7)</p>	<p>Figure 2-5: Graco AL Airless Spray Gun (http://www.graco.com/Internet/T_PDB.nsf/SearchView/ALSeriesAutomatic)</p>

Electrical Work

The electrical work consisted of designing, specifying, and purchasing the servo control system and electrical power supply, and installing these components on the structure and connecting them to the motion control components to form a functional robotic system.

Servo Control System: Based on a knowledge of previous projects of this nature it was determined that the best alternative for a servo control system was available from Galil Motion Control. A decision was made to purchase the Galil DMC-2143 motion controller with an integral AMP-20540 four-channel servo amplifier (Figure 2.6).

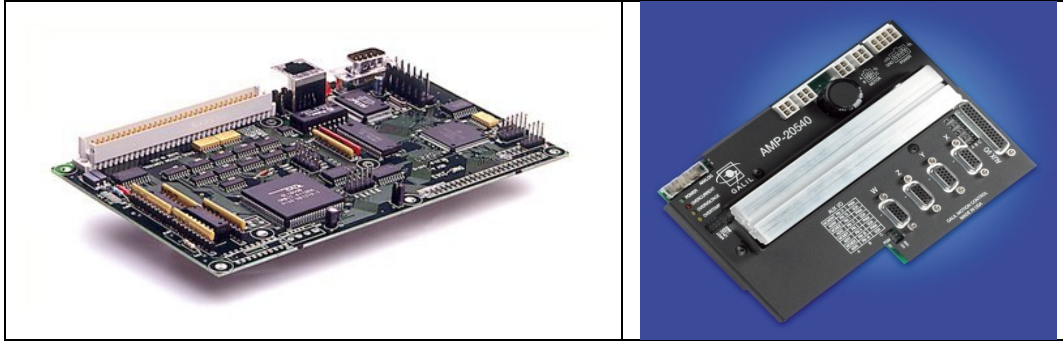


Figure 2-6: Galil Motion Control Board and Amplifier
(<http://www.galilmc.com/products/dmc-21x3.php>)

Power Supply: The Galil equipment was specified to run off of a single 48 VDC power supply, so a 3000 watt 48 VDC switching power supply was purchased to provide power to the motion control equipment. The source for this supply, as well as the paint pump, the air compressor, and the laptop computer used for programming the system was 120 VAC, so the system could simply be plugged into an outlet, or operated off of a generator. A Generac GP 3250 watt portable generator was purchased to provide a mobile supply of power for testing purposes.

Final Assembly: All of the mechanical and electrical components were then assembled and interconnected into a functional robotic system (Figure 2.7). The system was extensively tested to demonstrate that all systems were working properly, and to enable us to become familiar with the mechanical and electrical behavior of the device.



Figure 2-7: Assembled Robotic Painter Prototype

Software Work

The software work consisted of developing motion programs for each character or symbol, and developing an operator interface for the device.

Motion Programs: The Galil motion controller uses the DMC (Direct Motion Control) language and that is what was used to develop the motion programs. Programs were written and tested for all of the letters of the alphabet and for the words STOP, SLOW, TURN, and XING. Programs were also written for straight, left turn, right turn, and straight/left combination and straight/right combination arrows. In addition, programs were written for painting symbols, including handicap parking, bike lane, and railroad crossing markings. Programs were based on the markings as defined in the *Manual of Uniform Traffic Control Devices for Streets and Highways* [3]. Some specialty programs were also developed to test painting speed, accuracy, and coverage under various conditions.

User Interface: A software package called “Think & Do Live!” was purchased to provide a platform for developing the user interface. This software has drivers that seamlessly interface with the Galil motion control system so development time was minimized. An interface was developed so any program could be selected and run, and so the progress of the painting could be monitored. The interface was run on a laptop computer which was connected to the Galil motion control system via an Ethernet connection.

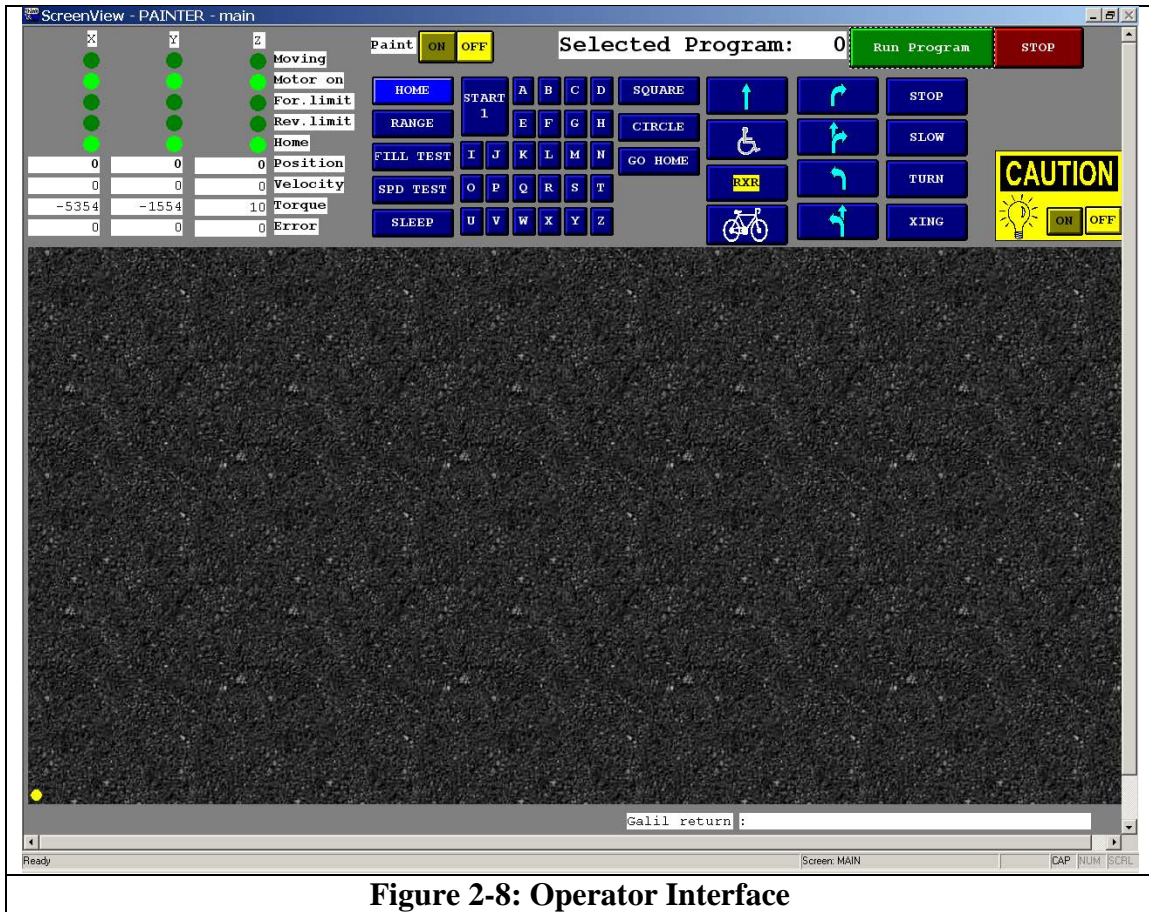


Figure 2-8: Operator Interface

Testing

The device was first tested for proper operation and any changes or adjustments necessary were made. Other tests were then run to determine the optimal values for several parameters, including air actuation pressure, paint pressure, painting speed, and paint coverage. Finally, all of the motion programs were tested to demonstrate the capabilities of the machine to paint letters and symbols on the roadway. The painting tests were done with standard latex pavement marking paint. The majority of the painting tests were done indoors on canvas and heavy textured paper, but some were conducted outside on actual pavement.

Chapter 3: Results and Conclusions

System Test Results: Several tests were performed to determine the maximum or optimal values for mechanical and electrical parameters in the system. The results of these tests were as follows:

- Maximum paintable area 98 in. x 47 in. (2.5 m x 1.2 m)
- Optimal painting speed 12 in./sec. (300 mm/sec)
- Optimal painting width 4 in. (100 mm)
- Optimal paint pressure 2500 psi (17.5 MPa)
- Actuation air pressure range 80-100 psi (.56-.70 MPa)
- Maximum power demand 3000 W

Painting Results: All of the motion programs were tested to demonstrate the capabilities of the machine to paint letters and symbols on the roadway. The results of some of the tests are shown in Figure 3.1.

Conclusions: A large-scale prototype of a robotic device for painting symbols and messages on the roadway was constructed and tested. The device has clearly demonstrated the feasibility of using robotics to paint roadway markings and has helped to determine many of the design parameters necessary to develop a commercially viable unit. The device can be controlled from a laptop computer at a safe distance by a single operator. Expected benefits of the deployment of such a device include improved operator safety, improved productivity, and improved flexibility in roadway marking operations.



Letters



Right/Straight Combo Arrow



Left Turn Arrow



Bicycle Lane

Figure 3-1: Painting Results

References

1. Advanced Highway Maintenance and Construction Technology Research Center, University of California Davis (Internet), *Stenciling Machine and General Purpose Sign Painting System*, (Accessed 10/15/2007), <http://www.ahmct.ucdavis.edu/index.php?title=OtherMarkersSigns>
2. D. Hong, W. Lee, B. Chu, and T. Kim, "Gantry Robot with Extended Workspace for Pavement Sign Painting Operations," *Journal of Mechanical Science and Technology*, Vol. 19, no. 6, 1268-1279 (2005).
3. U.S. Department of Transportation, Federal Highway Administration, *Manual of Uniform Traffic Control Devices for Streets and Highways*, 2009 Edition, USDOT-FHA, Washington, D.C.